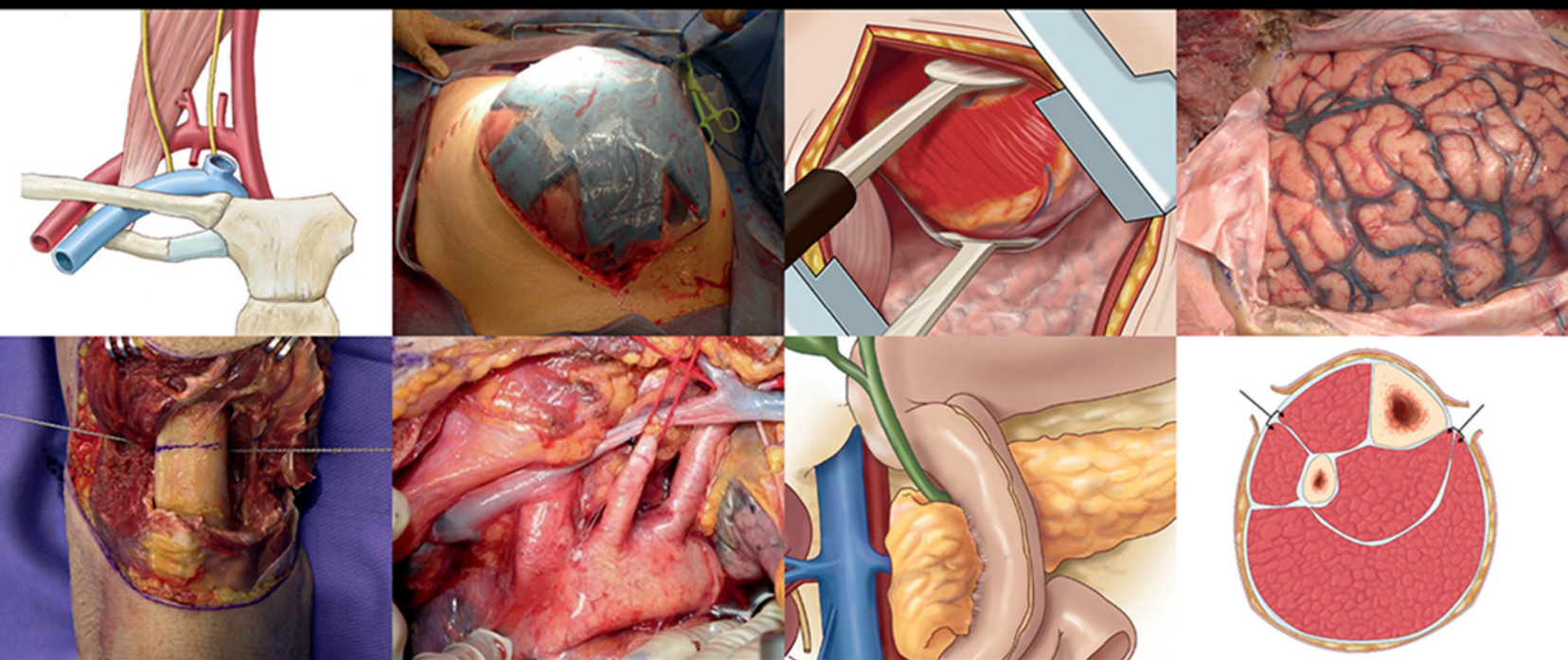


SECOND
EDITION

ATLAS OF SURGICAL TECHNIQUES IN TRAUMA



EDITED BY
Demetrios Demetriades
Kenji Inaba
George Velmahos

CAMBRIDGE

Medicine

Atlas of Surgical Techniques in Trauma

Second Edition

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Edited by

Demetrios Demetriades

University of Southern California

Kenji Inaba

University of Southern California

George C. Velmahos

Harvard University



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To my parents, my wife Elizabeth, my daughters Alexis and Stefanie, and my son Nicholas.

D. Demetriades

To my parents, wife Susie, and son Koji.

K. Inaba

To the drivers of my inspiration: my parents, my wife, and children.

G. C. Velmahos

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Contributors

James Bardes, MD

Trauma Fellow and Instructor in Surgery, University of Southern California; Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Elizabeth R. Benjamin, MD, PhD, FACS

Associate Professor of Clinical Surgery, Division of Trauma, Emergency Surgery, and Surgical Critical Care, Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Charles D. Best, MD, FACS

Associate Professor of Urology and Surgery, University of Southern California; Chief of Surgery, Grays Harbor Community Hospital, Aberdeen, WA, USA

Sigita Cahoon, MD, MPH, FACOG

Assistant Professor of Clinical Obstetrics and Gynecology, University of Southern California; Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Vincent Chong, MD, MS

Trauma and Critical Care Fellow, Division of Trauma, Emergency Surgery, and Surgical Critical Care, Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Marcia Ciccone, MD

Assistant Professor of Clinical Obstetrics and Gynecology, University of Southern California; Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Damon Clark, MD

Assistant Professor of Surgery, University of Southern California; Department of Trauma, Emergency Surgery, and Surgical Intensive Care, Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Demetrios Demetriades, MD, PhD, FACS

Professor of Surgery, University of Southern California; Director of Trauma, Emergency Surgery, and Surgical Intensive Care Unit, Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Leo R. Doumanian, MD

Associate Professor of Clinical Urology, Keck School of Medicine of USC, USC Institute of Urology, Los Angeles, CA, USA

Matthew J. Forestiere, MD

Trauma Fellow and Clinical Instructor in Surgery, Division of Trauma, Emergency Surgery, and Surgical Critical Care, Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Warren Garner, MD, MS, FACS

Director LAC+USC Burn Center; Professor of Surgery, University of Southern California, Los Angeles, CA, USA

Rondi Gelbard, MD, FACS

Assistant Professor of Surgery, Emory University School of Medicine; Associate Medical Director, Surgical Intensive Care Unit; Associate Program Director, Surgical Critical Care Fellowship; Emory Department of Surgery at Grady Memorial Hospital, Atlanta, GA, USA

Justin Gillenwater, MD, MS

Assistant Professor, Plastic and Reconstructive Surgery, University of Southern California; Co-Director, LAC+USC Regional Burn Center, Los Angeles, CA, USA

Daniel Grabo, MD, FACS

Associate Professor of Surgery, West Virginia University, Morgantown, WV, USA

Peter Gruen, MD

Associate Professor of Neurosurgery, University of Southern California; Associate Medical Director, Critical Care, Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Peter M. Hammer, MD, FACS

Assistant Professor of Surgery, Indiana University School of Medicine; Associate Trauma Medical Director, Indiana University Health Methodist Hospital, Indianapolis, IN, USA

Kenji Inaba, MD

Professor of Surgery, University of Southern California; Vice Chair and Residency Director, Los Angeles County and University of Southern Medical Center, Los Angeles, CA, USA

Emilie Joos, MD, FRCSC, FACS

Clinical Assistant Professor, Trauma and Acute Care Surgery Fellowship Program Director, Department of Surgery, University of British Columbia, Vancouver, BC, Canada

Mark J. Kaplan, MD, FACS

Clinical Professor of Surgery, Kimmel School Medicine, Thomas Jefferson University; Associate Chairman Surgery, Einstein Medical Center Philadelphia; Chairman, Division of Trauma, Surgical Critical Care, and Acute Care Surgery, Einstein Medical Center, Philadelphia, PA, USA

Jessica A. Keeley, MD

Trauma Fellow, Division of Trauma, Emergency Surgery, and Surgical Critical Care, Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Anthony W. Kim, MD, MS, FACS

Jeffrey P. Smith Endowed Chair in Surgery, Professor of Clinical Surgery, Chief, Division of Thoracic Surgery, Keck School of Medicine, The University of Southern California, Los Angeles, CA, USA

Edward Kwon, MD, FACS

Trauma Surgery and Surgical Critical Care, St. Francis Medical Center, Lynwood, CA, USA

Lydia Lam, MD, FACS

Assistant Professor of Clinical Surgery and Emergency Medicine, Associate Program Director, Surgical Critical Care Fellowship, LAC+USC Medical Center, Los Angeles, CA, USA

Jackson Lee, MD

Associate Professor of Clinical Orthopedics, Keck School of Medicine of University of Southern California; Service Chief, Orthopedics, LAC+USC Medical Center, Los Angeles, CA, USA

Meghan Lewis, MD, FACS

Assistant Professor of Surgery, University of Southern California; Associate Director, Surgical Intensive Care Unit, Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Bryan Love, MD

Trauma Fellow and Clinical Instructor, Division of Trauma, Emergency Surgery, and Surgical Critical Care, Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Gregory A. Magee, MD, MSc

Assistant Professor of Surgery, Division of Vascular Surgery and Endovascular Therapy, Keck Medical Center, University of Southern California, Los Angeles, CA, USA

Kazuhide Matsushima, MD, FACS

Assistant Professor of Clinical Surgery, University of Southern California; Division of Acute Care Surgery, LAC+USC Medical Center, Los Angeles, CA, USA

Brian Mecklenburg, MD

Anesthesiologist/Intensivist, Commander US Navy; Instructor, Navy Trauma Training Center, USA

Laila I. Munderspach, MD

Professor, Department of Obstetrics and Gynecology, Keck School of Medicine of University of Southern California, Los Angeles, CA, USA

Nick A. Nash, MD, FACS

Associate Professor of Surgery, Director of Surgical Critical Care, University of Louisville, Louisville, KY, USA

Eric Pagenkopf, MD

Captain (Retired), US Navy, USA

Caroline Park, MD

Trauma and Critical Care Fellow, Division of Trauma, Emergency Surgery, and Surgical Critical Care, Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Travis M. Polk, MD, FACS

Assistant Professor of Clinical Surgery, Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California; Director, Navy Trauma Training Center, LAC+USC Medical Center; Commander, US Navy, Los Angeles, CA, USA

Vincent L. Rowe, MD, FACS

Professor of Surgery, Division of Vascular Surgery and Endovascular Therapy, Keck School of Medicine of University of Southern California, Los Angeles, CA, USA

Morgan Schellenberg, MD, MPH, FRCSC

Assistant Professor of Surgery, University of Southern California; Division of Trauma and Surgical Critical Care, Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Lisa L. Schlitzkus, MD, FACS

Assistant Professor of Surgery, University of Nebraska Medical Center; Trauma Medical Director, Nebraska Medicine, Omaha, NE, USA

Jennifer A. Smith, MD, FACS

Assistant Professor of Surgery, David Geffen School of Medicine at UCLA; Associate Chief of Trauma, Acute Care Surgery, and Surgical Critical Care, Harbor-UCLA Medical Center, Los Angeles, CA, USA

Aaron Strumwasser, MD, MSc, FACS

Assistant Professor of Clinical Surgery, Division of Trauma, Acute Care Surgery, and Surgical Critical Care, Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Matthew D. Tadlock, MD, FACS

Assistant Professor of Surgery, Uniformed Services University of the Health Sciences; Head, Acute Care Surgery, Department of Surgery, Naval Medical Center San Diego, San Diego, CA, USA; Commander, Medical Corps, US Navy, USA

Peep Talving, MD, PhD, FACS

Professor of Surgery, University of Tartu; Director, Acute Care Surgery, North Estonia Medical Center, Tallinn, Estonia

Pedro G. Teixeira, MD, FACS, FSVS

Associate Professor of Surgery, Department of Surgery and Perioperative Care, Dell Medical School, University of Texas at Austin, Austin, TX, USA

Stephen Varga, MD, FACS

Assistant Professor of Surgery, University of Maryland; Director of Physician Education, R Adams Cowley Shock Trauma Center, University of Maryland Medical Center, Baltimore, MD, USA

George C. Velmahos, MD, PhD, MEd

John F. Burke Professor of Surgery, Harvard Medical School; Chief of Trauma, Emergency Surgery, and Surgical Critical Care, Massachusetts General Hospital, Boston, MA, USA

Kelly Vogt, MD, MSc, FRCSC

Assistant Professor of Surgery, Western University; Associate Medical Director – Trauma Program, London Health Sciences Centre, London, ON, Canada

Zachary D. Warriner, MD

Trauma Fellow and Clinical Instructor in Surgery, Division of Trauma, Emergency Surgery, and Surgical Critical Care, Los Angeles County and University of Southern California Medical Center, Los Angeles, CA, USA

Paul Wisniewski, MD

Assistant Professor of Clinical Surgery, Division of Trauma, Emergency Surgery, and Surgical Critical Care, University of Southern California; Commander, US Navy, Los Angeles, CA, USA

Gabriel Zada, MD, MS, FAANS, FACS

Associate Professor of Neurosurgery, University of Southern California, Los Angeles, CA, USA

Foreword

Many books come and go; anatomy books have existed since the sixteenth century and have been the basis of expert surgical exploration during surgical disease management. A surgeon's knowledge of anatomy in trauma is based on the need to expose a wide variety of areas of the body that are often not learned through traditional dissection or elective surgery. The path of a bullet or the extreme energy transfer during blunt trauma can cause damage to structures that require exposures not normally encountered. The decision making in picking the right incision, understanding the anatomic relationships that can be exposed, and knowing the moves to get to a critical area of injury are often times what determines success or failure (even life or death), particularly when the patient is bleeding.

The current second edition of the book *Atlas of Surgical Techniques in Trauma* by Demetriades, Inaba, and Velmahos fills a void that has existed for several decades. The current atlas approaches trauma from the standpoint of the possible exposures and relevant anatomy that are needed when encountering a specific anatomic injury.

For each area, the surgical anatomy is reviewed in classic terms, but augmented with cadaveric vascular injections showing the anatomic structures with very clear photographs complementing traditional anatomic drawings. The relevant points of anatomy in the context of a clinical injury or during exposure are emphasized. The general principles of what can be done to manage an injury are included: the appropriate incision, a step-wise approach during exposure emphasizing anatomy, which structures might be injured, which structures

might be divided or ligated, and any specific goals of the operation.

A student using this book should be able to mentally rehearse and in fact visualize many of the structures that they may not have previously encountered. When accompanied by participation in cadaveric dissections, this should prepare the surgeon to encounter injuries which they may see infrequently. Dr. Demetriades and his co-authors have anticipated how important this challenge is to a trauma surgeon and have presented this knowledge in a wonderful text, which will serve many generations in the future.

The award-winning first version was translated into many languages, having a major impact around the world. I have no question that this version will be even more widely received. At a time when medical education is increasingly about efficiency, (with less time spent on classic subjects like anatomy) the need for understanding clinically relevant anatomy has never been greater.

This is truly a book that every surgeon who will ever encounter these kinds of clinical challenges should use. Own a copy and commit these wonderful photographs and principles to memory. You will find yourself well prepared when encountering these kinds of injuries. Your patients will benefit from this essential knowledge.

David B. Hoyt, MD, FACS
Executive Director, American College of Surgeons

Preface

The second edition of the *Atlas of Surgical Techniques in Trauma* provides a practical companion in the operating room to the surgeons who provide care to the injured. It is designed to be a rapid, highly visual summary of the critical anatomy, procedural sequencing, and pitfalls associated with these procedures. We believe that it will be a good companion for trainees as well as those in practice and in the military, as a rapid review of both common and uncommonly performed procedures.

The atlas is organized into chapters and sections according to anatomical areas. The text is written in a bulleted, reader-friendly format, and includes practical surgical anatomy, general principles, exposures, definitive management and technical tips, and pitfalls. It includes more than 900 high-quality photographs and illustrations, produced while performing

these procedures on fresh, perfused, and ventilated human cadavers at the USC Fresh Tissue Dissection Lab. The surgical techniques are shown step by step and with visual details that inform the reader accurately about the critical elements of each procedure.

Whereas these operations represent broadly applied standards of care, many specific details reflect the philosophy of the editors and the authors, all of whom bring their individual, extensive, real-world clinical experience to each chapter. It is, therefore, possible that different ways exist to access and control injured structures. However, the ways described here are tested and proven successful. As such, they belong to every surgeon's armamentarium, when one is called to save the life of an injured patient in need of an operation.

Acknowledgments

The authors greatly acknowledge the major contributions of Alexis Demetriades, scientific illustrator, and Michael Minneti, for coordinating and helping with the anatomical dissections and photos in the Fresh Tissue Dissection Lab.

Trauma Operating Room

Brian Mecklenburg, Lisa L. Schlitzkus, and Kenji Inaba

General Principles

- A large operating room (OR) situated near the emergency department, elevators, and ICU should be designated as the Trauma OR to facilitate the logistics of patient flow and minimize transport. The room should be securable for high profile patients.
- A contingency plan for multiple simultaneous operations should be in place with the operating rooms in sufficient proximity to allow nursing and anesthesia cross-coverage and facilitate supervision of the surgical teams. Direct lines of communication between the OR, resuscitation area, ICU, other ORs, blood bank, and laboratory should be in place.
- All rooms should have ample overhead lighting as well as access to portable headlamps.
- Multiple monitors to display imaging, vital signs, and laboratory such as thromboelastometry, should be in place.
- Hybrid operating and interventional radiology teams should be familiar with operating in the hybrid room.
- A dedicated family waiting room should be identified, and all family should be directed to this area for the postoperative discussion.



Figure 1.1 The trauma operating room should be spacious in order to allow multiple surgical teams operating simultaneously. Multiple and large monitors should display vital signs, images, and laboratory results.

(a)



(b)



Figure 1.2 (a) A hybrid operating room is highly valuable in severe multitrauma. Surgical teams and angiointervention specialists can work simultaneously without having to move the patient to the radiology suite. (b) Management of a multitrauma patient with a severe liver injury and a complex pelvic fracture. A combination of damage control surgery and angioembolization was performed.

Setup and Equipment

- Nursing staff should be regularly in-serviced about the trauma room setup, supplies, and common practices such as massive transfusion to minimize problems due to service line cross-coverage.
- While all attempts should be made to count instruments and ensure a correct final count, this may be postponed in life-threatening or damage control situations. Radio-frequency ID device embedded laparotomy sponges are a useful adjunct to these emergency situations.

The following should be readily available:

- Instrument trays including: laparotomy, sternotomy with pneumatic sternal saw, thoracotomy, emergency airway, amputation, and peripheral vascular.
- A wide selection of vascular shunts, catheters, vascular conduits, chest tubes, drain, staples, local hemostatic agents, advanced thermal cutting devices, and temporary abdominal closure supplies.
- Standard suture tree, including sternal closure wires, vascular sutures, and liver sutures.
- Adult and pediatric code cart
- The ability to provide cardiac pacing via transcutaneous, transvenous, or intramyocardial means.
- High-volume suction canister and device
- Tourniquets
- Endotracheal tube occluders
- Rigid sigmoidoscope, bronchoscope, gastroscope
- REBOA (Resuscitative Endovascular Balloon Occlusion of the Aorta) Catheters
- Portable fluoroscopy and personnel shielding devices should be immediately available for use in the OR
- The electrothermal bipolar vessel sealing system device (LigaSure device) is desirable

Warming

- Due to the large surface area exposed, trauma patients are susceptible to hypothermia
- The room should not be cold
- Forced air warmers and blankets should be used
- Warmed intravenous fluids should be available at all times
- All irrigation fluids should be warmed

Blood

- A type and screen should be sent immediately to the laboratory upon patient arrival at the emergency department.
- Emergency release products (uncross-matched O– or O+ packed red blood cells as well as thawed AB or low titer

plasma) should be readily available in the emergency department and in the operating room.

- A rapid transfusion device should be available. An active discussion with anesthesia and OR nursing staff is beneficial regarding the specific type of rapid transfusion device employed in your hospital (e.g. Level One vs. Belmont rapid transfusion device).

Communication with Anesthesia Team

- Ensure open communication with anesthesia team during surgery. If possible, communicate with responsible head anesthesiologist by name. Set the tone early with all team members, particularly anesthesia and OR nurse, communicating that you require all team members to provide appropriate information to achieve a shared mental model.
- Appreciate that while a large OR can become crowded quickly, the anesthesia team must have sufficient space and access to the patient, anesthesia machine, and blood

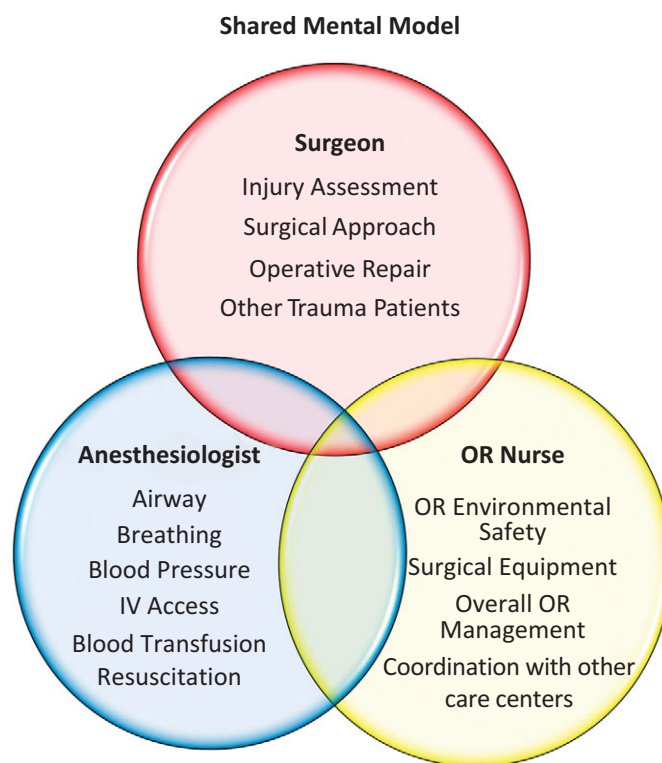
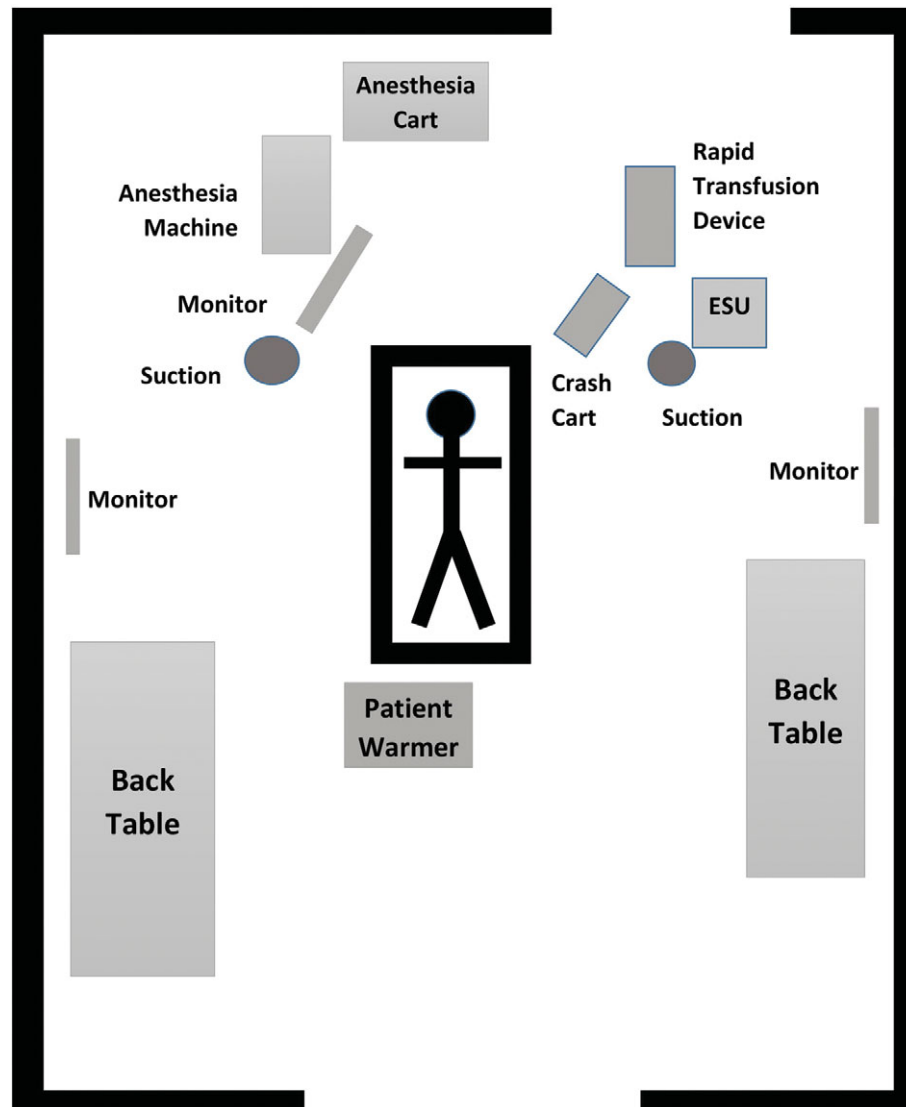


Figure 1.3 The Operating Room is a dynamic environment requiring excellent communication and teamwork for best outcomes of the trauma patient. Constant and effective communication is essential in order to optimize care.

transfusion equipment. Anesthesia should also have ready egress and ingress out of the OR for delivery of blood products, labs, and unanticipated special equipment.

Figure 1.4 A proposed functional setup of the operating room teams, equipment, and supplies.



- If time permits, prior to surgical start, provide brief discussion of awareness of current intravascular access and plan for further access (e.g. large bore internal jugular, large bore subclavian, Rapid Infusion Catheters, large bore peripheral IV, or intra-osseous line).
- If the patient is not yet intubated, a discussion of intravascular access and blood products administered up to this point may prevent catastrophic hemodynamic collapse with anesthetic induction and may facilitate more rapid establishment of intravascular access and blood product administration.
- Recognize that many times the surgeon can achieve intravascular access (subclavian or femoral sites) as the anesthesia team is preparing the patient (moving to table, placing monitors, ensuring appropriate life support measures, etc.). Intravascular access areas can also be prepped into the surgical field to expedite large bore access and surgical start.

- As the case begins, continue to establish an open atmosphere for communication with specifics of intraoperative resuscitation to include administered blood products, degree of hemodynamic instability, and surgical management plan as it develops (Figure 1.2).
- When appropriate, communicate ability to temporarily slow down hemorrhage through packing, manual compression, aortic cross clamp, or REBOA, if anesthesia team is having difficulty maintaining an adequate pressure or perfusion without vasopressors. This can provide the anesthesia team time to transfuse blood products instead of resorting to vasopressors.
- Additional personnel are often available to assist with blood product administration. Again, a brief discussion with entire OR team can result in more useful personnel resources arriving.
- At a point when hemodynamic control has been established, a brief pause and thoughtful discussion with anesthesia will ensure a shared mental model of the patient's hemodynamic status and progress in resuscitation.
- After surgery has concluded, an informal debrief with the anesthesia team can result in enhanced teamwork and future improvement in intraoperative resuscitation.

Cricothyroidotomy

Morgan Schellenberg, Paul Wisniewski, and Travis M. Polk

Surgical Anatomy

- The cartilaginous and bony structures of the larynx include the hyoid bone as well as the thyroid and cricoid cartilages. The trachea begins below the cricoid cartilage.
- The hyoid bone, thyroid cartilage, and tracheal cartilages are incomplete rings, with posterior membranous walls. In contrast, the cricoid cartilage is a complete ring, forming an important structural attachment for muscles and ligaments of the larynx. The cricoid cartilage ensures airway patency by stenting the larynx open.
- The cricothyroid membrane is situated between the thyroid and cricoid cartilages in the midline anteriorly. It is located directly beneath the skin, providing direct and easy access to the airway. This membrane is bordered superiorly by the thyroid cartilage, inferiorly by the cricoid cartilage, and laterally by the paired cricothyroid muscles. In adults, it is approximately 1 cm tall and 2–3 cm wide.
- The vocal cords are enclosed within the thyroid cartilage, approximately 1 cm from the upper border of the cricothyroid membrane.
- The cricothyroid membrane is about four fingerbreadths from the suprasternal notch.

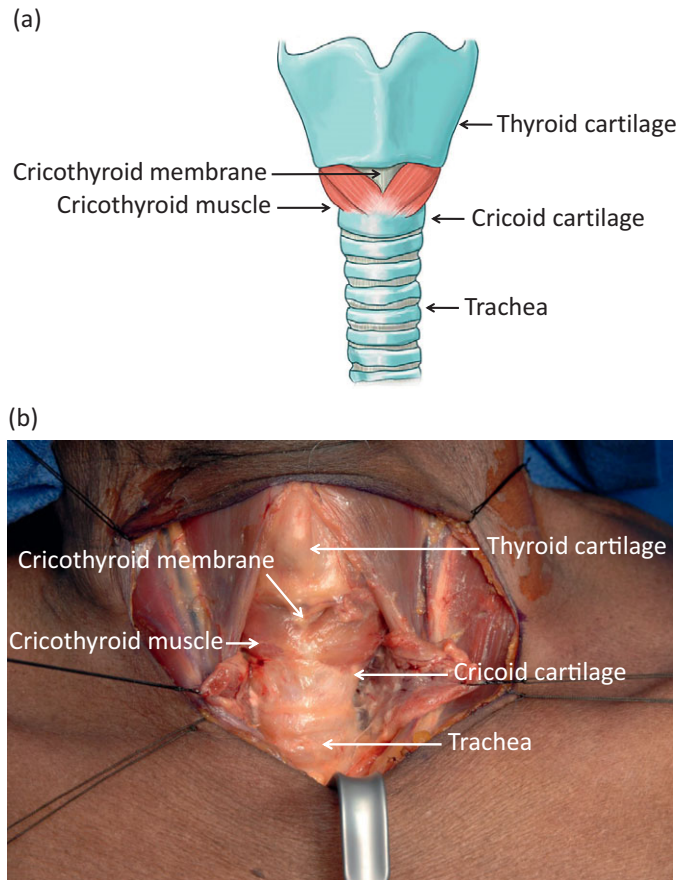
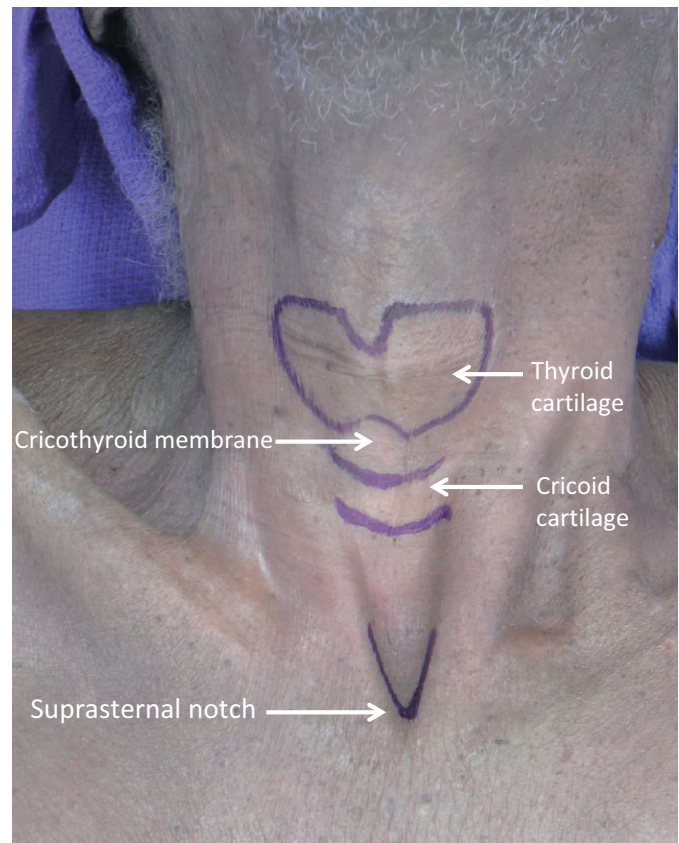


Figure 2.1 Anatomy of the larynx. (a, b) Anatomy of the cricothyroid space: The cricothyroid space is formed by the inferior border of the thyroid cartilage and the superior border of the cricoid cartilage. It is partially covered laterally by the cricothyroid muscles. In adults, the cricothyroid membrane is about 1 cm in height and 2–3 cm wide.

General Principles

- A cricothyroidotomy is the emergency surgical airway of choice when attempts at orotracheal intubation or airway rescue techniques, such as the laryngeal mask airway (LMA), have failed.
- The choice of open versus percutaneous technique is determined by personal preference and experience.
- The rapid identification of surface landmarks is critical. In most patients, the thyroid notch is easily visualized or at least palpated in the anterior midline. Palpation immediately caudal to the thyroid cartilage reveals a soft depression, the cricothyroid membrane, which is the target for cricothyroidotomy.
- In some patients, this anatomy can be obscured. This may occur in obese patients and those with neck trauma, especially in the presence of a large hematoma. In these patients, the four-finger technique provides a rapid and easy way of estimating the location of the cricothyroid membrane. With the operator's four fingers extended side by side, the small finger of the hand is placed against the patient's sternal notch. The surgeon's index finger is then pointing at incision site, at the cricothyroid membrane.

(a)



(b)

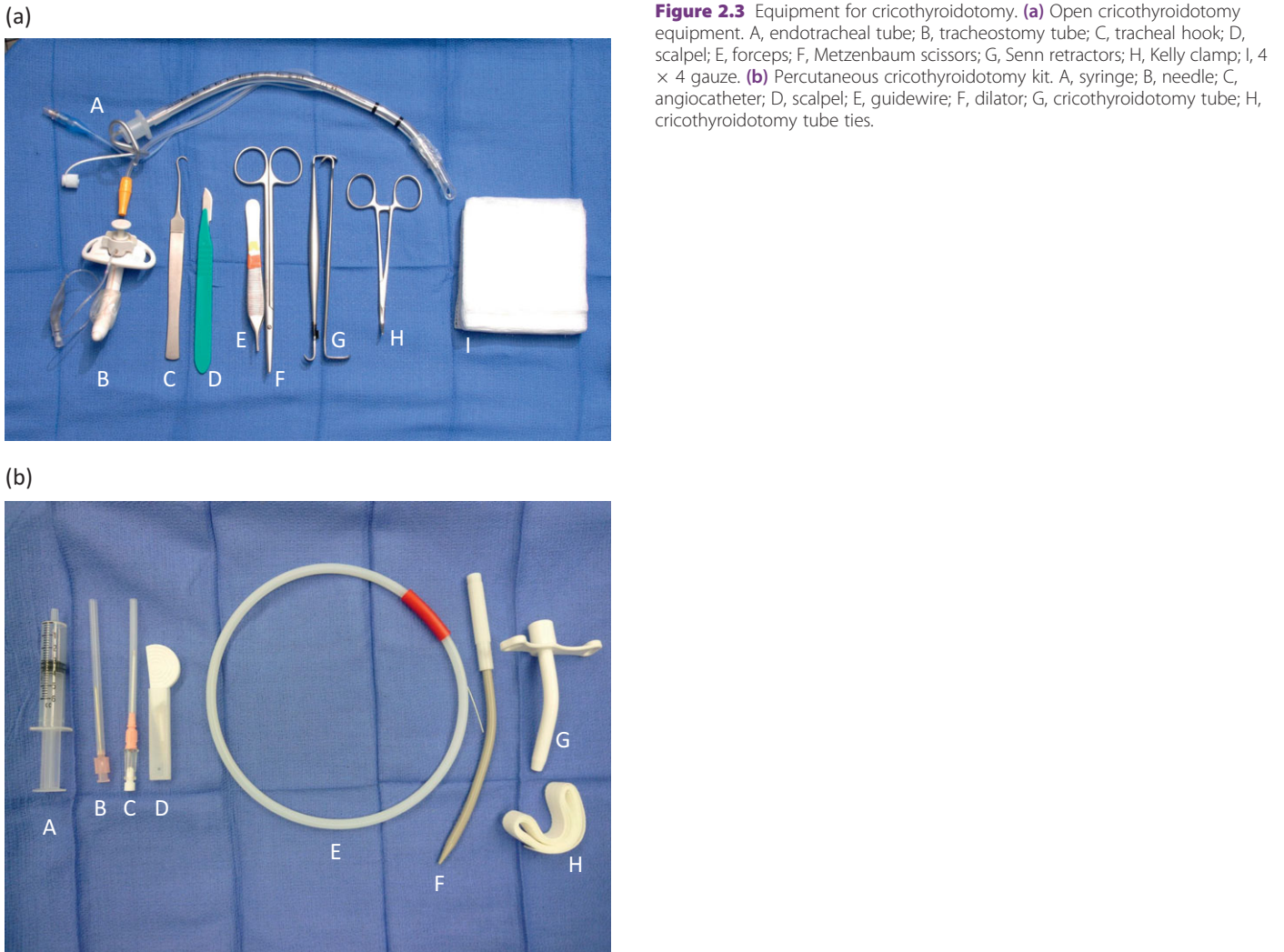


Figure 2.2 External landmarks for cricothyroidotomy. **(a)** Surface anatomy of the cricothyroid space. The cricothyroid space includes the inferior border of the thyroid cartilage and the superior rim of the cricoid arch. In adults, the cricothyroid membrane is about 1 cm in height and 2–3 cm wide. **(b)** The four-finger technique for identifying the cricothyroid membrane. With the palm extended, the tip of the small finger is placed in the suprasternal notch. The tip of the index finger touches the cricothyroid membrane in the midline.

- Cricothyroidotomy is relatively contraindicated in pediatric patients (less than 12 years of age), in whom the rates of long-term complications after cricothyroidotomy, particularly stenosis, are high. In these patients, transtracheal needle jet ventilation is preferred.
- Care should be taken when considering a cricothyroidotomy for patients with airway injuries. Suspected tracheal transection distal to the cricothyroid membrane is a contraindication to cricothyroidotomy.
- Routine conversion of cricothyroidotomy to tracheostomy is unnecessary.

Special Instruments

- The open cricothyroidotomy instrument set should include endotracheal tubes (size 6), scalpel, tracheal hook, Senn retractors, Kelly clamp, Metzenbaum scissors, and forceps. Alternatively, commercially available percutaneous cricothyroidotomy sets can also be used.
- Suction, appropriate lighting, and an end-tidal CO₂ detector should be available.



Patient Positioning

- If the cervical spine has been cleared, the neck should be extended. This brings the larynx anteriorly and facilitates access to the cricothyroid membrane. If cervical spine precautions must be maintained, a cricothyroidotomy can be performed with the neck in neutral position.

Technique of Open Cricothyroidotomy

- After landmarking the cricothyroid membrane as described above, stabilize the larynx with the nondominant

hand, using the index finger and thumb to place traction on the skin overlying the cricothyroid membrane.

- Make a vertical skin incision of approximately 3–4 cm in length, centered over the cricothyroid membrane. A vertical skin incision is preferred, as a transverse skin incision can damage the bilateral anterior jugular veins and result in bleeding, obscuring visualization and complicating the procedure. In experienced hands, a transverse incision is an acceptable option.

(a)

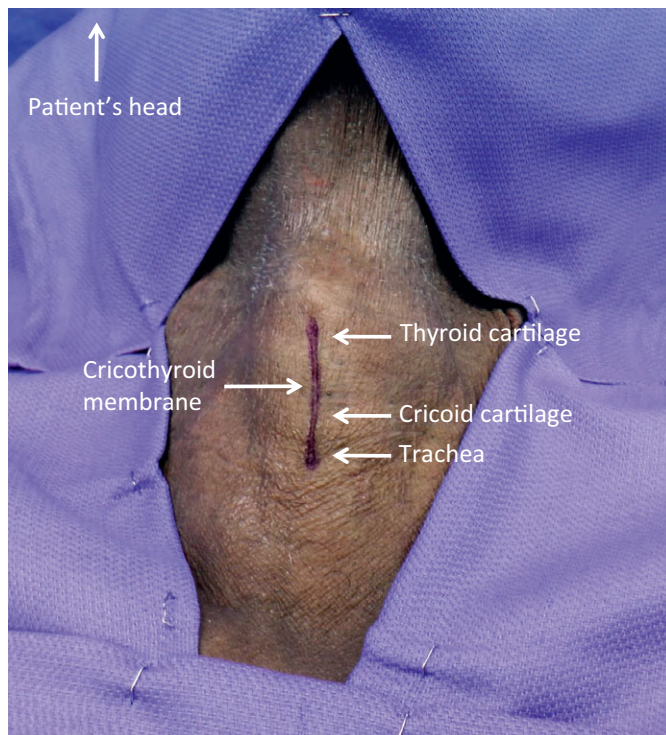
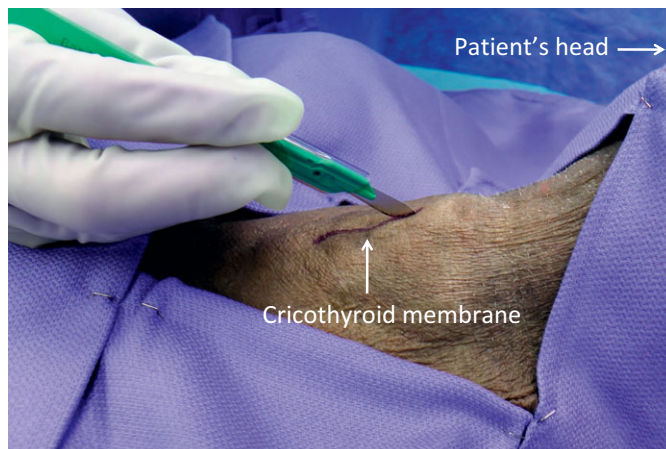


Figure 2.4 (a, b) Open cricothyroidotomy: skin incision. A vertical skin incision, approximately 3–4 cm in length, is made in the midline of the neck and centered over the cricothyroid membrane.

(b)



- After the skin incision, locate the cricothyroid membrane within the incision and then use the nondominant hand to stabilize the airway by grasping the larynx.
- With the scalpel, divide the cricothyroid membrane in a transverse orientation and extend the incision laterally approximately 1 cm to each side to the full width of the membrane. Perform the incision over the lower part of the cricothyroid membrane, along the superior border of the cricoid cartilage, in order to avoid injuring the cricothyroid artery which courses through the superior half of the cricothyroid membrane.

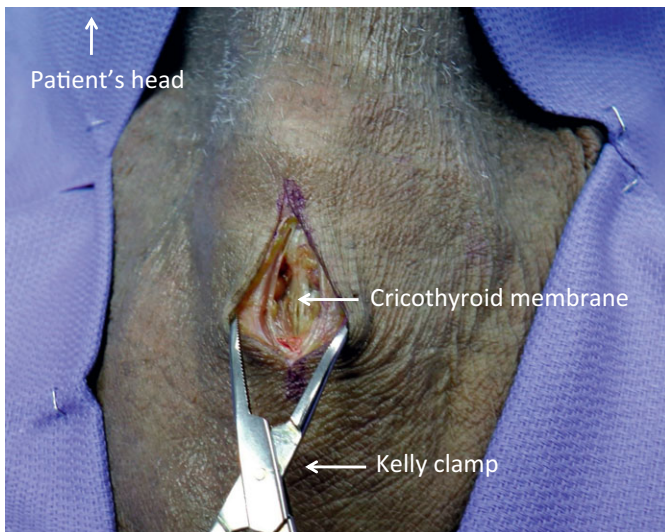


Figure 2.5 Identification of the cricothyroid membrane. The cricothyroid membrane is identified under the skin incision.

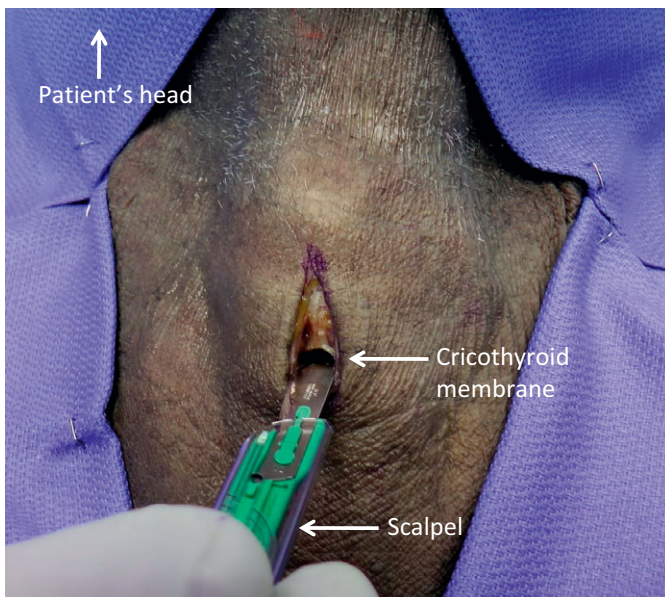
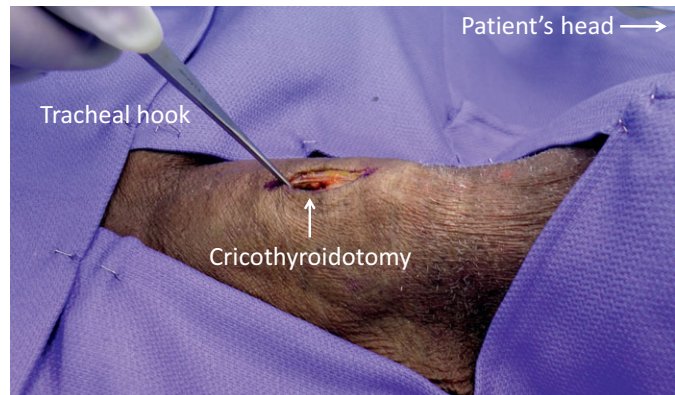


Figure 2.6 Incision of the cricothyroid membrane. The cricothyroid membrane is incised in a transverse orientation using a scalpel, creating the cricothyroidotomy.

- Insert the tracheal hook at the superior end of the cricothyroid incision and retract the thyroid cartilage cephalad and upwards. This maneuver immobilizes the trachea and keeps the cricothyroidotomy open.

(a)



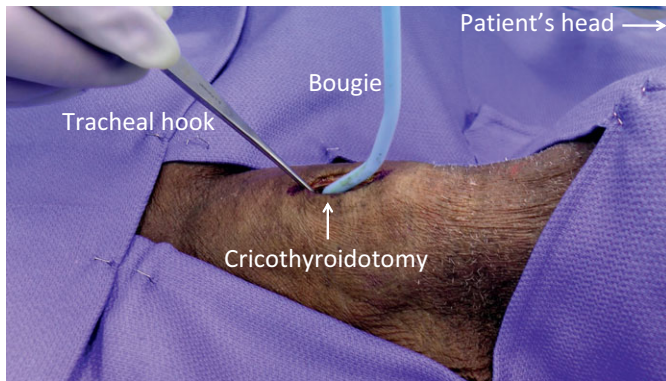
(b)



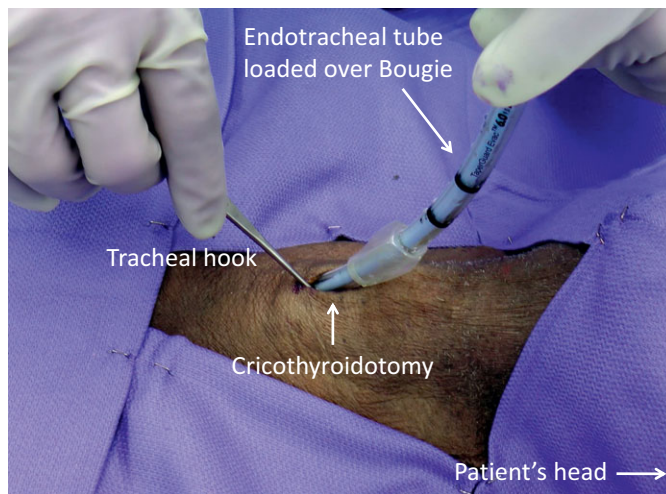
Figure 2.7 Tracheal hook. Following entry into the trachea, a tracheal hook is placed at the edge of the thyroid cartilage and firm retraction is applied upwards and towards the head (a). Alternatively, the tracheal hook may be placed inferiorly, on the cricoid ring with traction towards the patient's chest (b). Lifting upwards on the tracheal hook immobilizes the trachea and delivers the cricothyroidotomy into the field of view.

- A Bougie can now be passed into the airway towards the carina. The endotracheal or tracheostomy tube can be preloaded onto the Bougie, and then passed directly into the airway. Alternatively, instead of the Bougie, the obturator of the tracheostomy tube may be used for the insertion of the tube. Once seated in the airway, the inner cannula can be inserted.

(a)



(b)



(c)

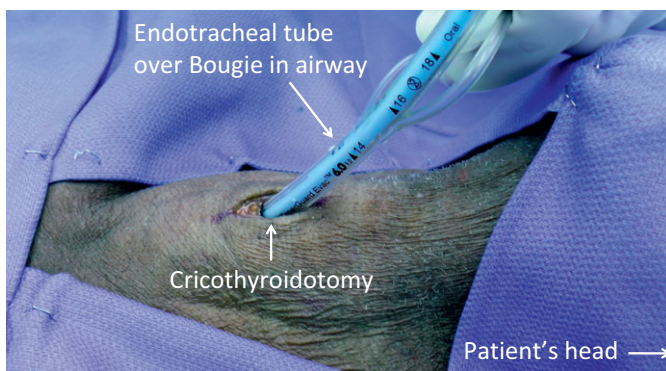


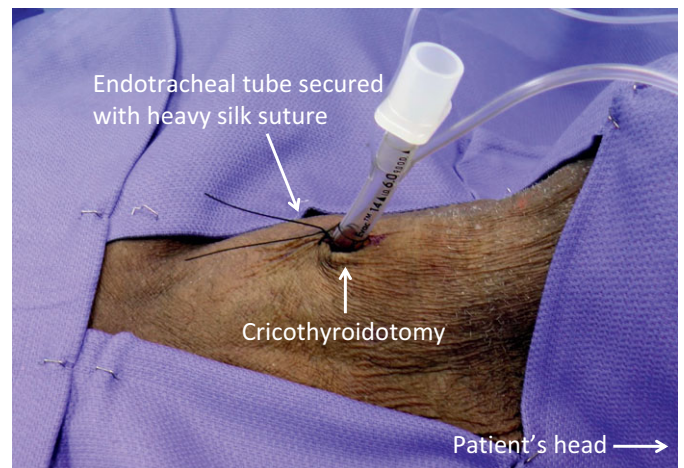
Figure 2.8 Bougie dilator and tube insertion. (a) Passage of a Bougie dilator through the cricothyroidotomy towards the carina can facilitate tube placement into the airway. (b, c) An endotracheal tube or tracheostomy tube can be preloaded onto the Bougie dilator and then inserted directly into the airway through the cricothyroidotomy.

- Once the tube is in the airway, the cuff is inflated with 10 cm³ of air. Confirm placement in the airway using a CO₂ detector and auscultation of bilateral breath sounds.
- Secure the tube in place with sutures. If a tracheostomy tube has been inserted, place the sutures directly through the tracheostomy appliance and apply tracheal ties. If an endotracheal tube has been inserted, a suture can be passed around it to secure it. Ventilation can then proceed.

Technique of Percutaneous Cricothyroidotomy

- Identify the cricothyroid space using the suprasternal notch, and the thyroid and cricoid cartilages as external landmarks. In patients with a short and thick neck or large hematomas, the cricothyroid space can be identified with the “four-fingers technique” as described above.
- Stabilize the thyroid cartilage between the thumb and the middle of the nondominant hand and make a small

(a)



(b)

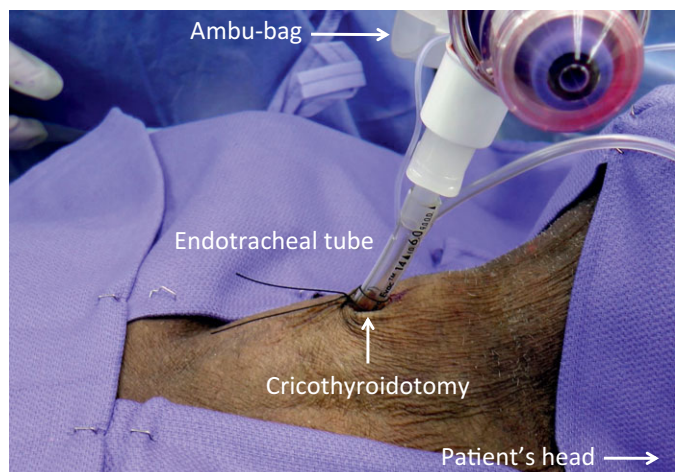


Figure 2.9 Securing the tube on the skin. The tube is secured in place using heavy silk suture.

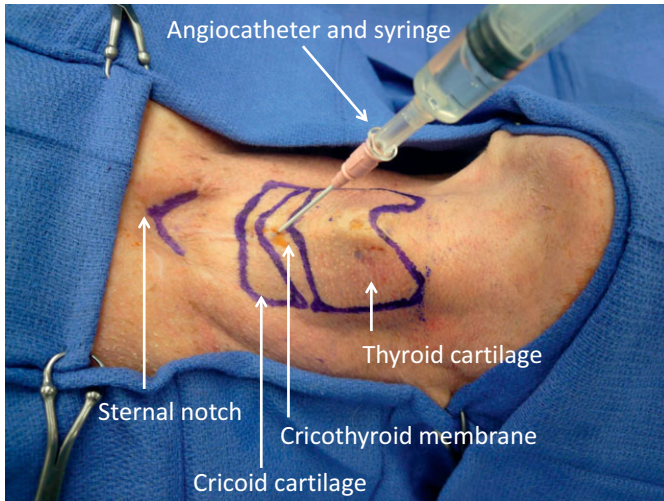
(5–10 mm) vertical skin incision, over the cricothyroid space.

- Insert the needle with angiocatheter, connected to a syringe prefilled with normal saline, into the airway through the cricothyroid membrane directed towards the carina, at a 45° angle to the skin.
- As the needle is advanced, apply negative pressure to the syringe. Entry into the trachea, is signaled by a distinct pop

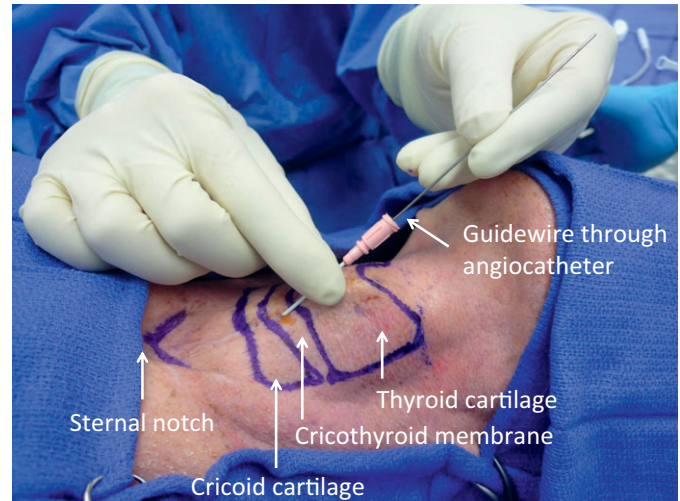
and confirmed by aspiration of air with bubbles in the syringe.

- Immobilize the angiocatheter overlying the needle in the airway with the nondominant hand and use the dominant hand to remove the needle and syringe and then thread the wire into the airway through the catheter in the cricothyroid membrane.

(a)



(b)



(c)

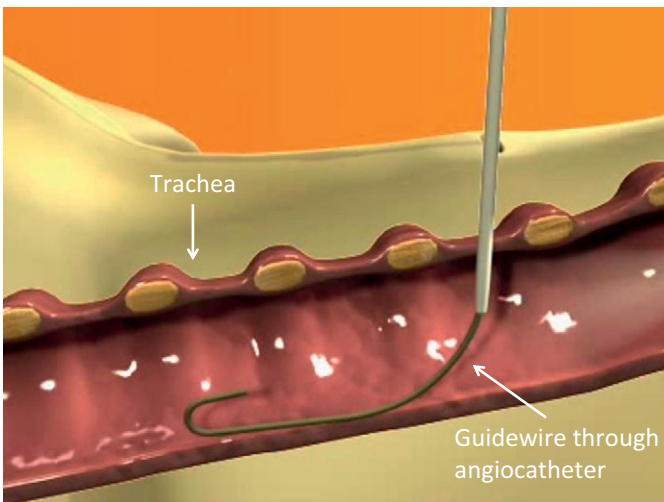
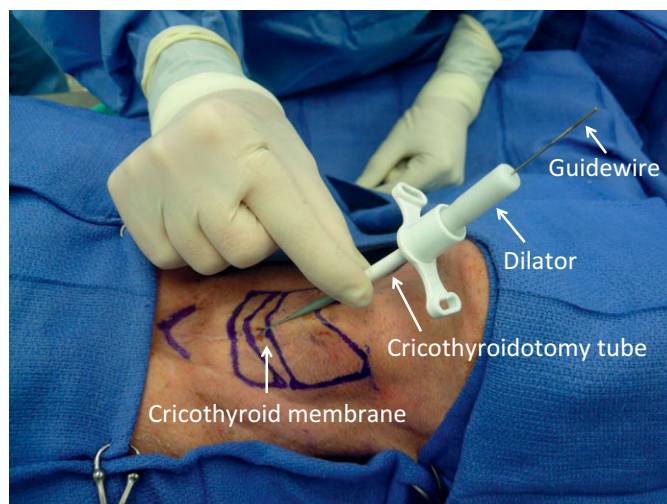


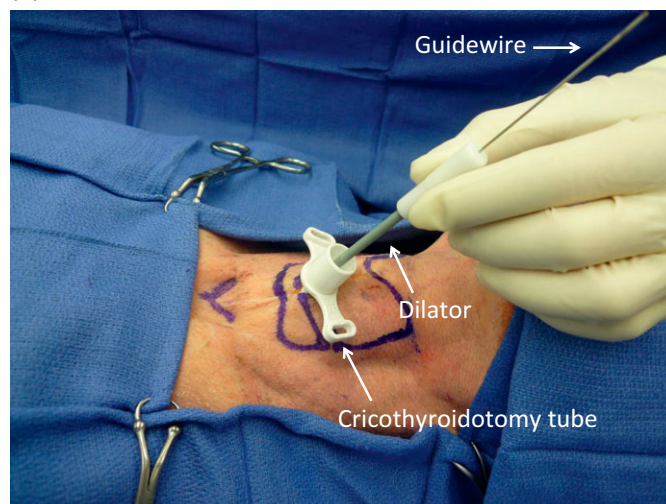
Figure 2.10 Percutaneous cricothyroidotomy. **(a)** A needle connected to a syringe of normal saline is inserted through the skin into the cricothyroid membrane at a 45° angle directed towards the carina. **(b, c)** After entry into the trachea, as suggested by the loss of resistance and confirmed by aspiration of air with bubbles into the syringe, the syringe is removed and the guidewire is advanced into the airway through the needle in the cricothyroid membrane.

- Preload the dilator into the lumen of the cricothyroidotomy tube and insert over the guidewire into the airway.
- Remove the dilator and the guidewire together once the cricothyroidotomy tube is in place.

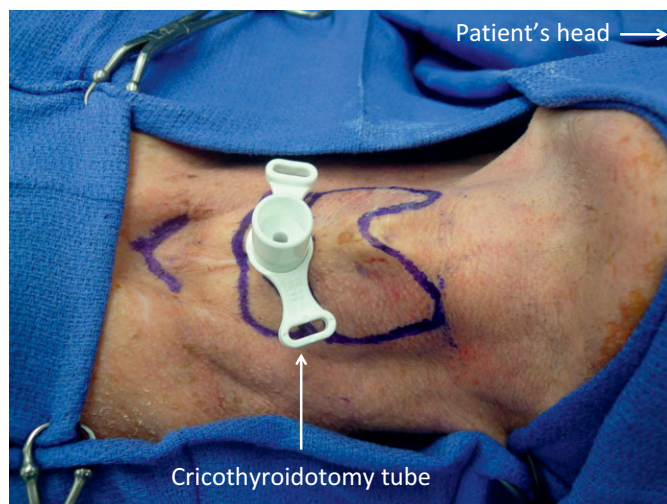
(a)



(b)



(c)



(d)



Figure 2.11 Inserting the cricothyroidotomy tube. **(a)** Preload. The cricothyroidotomy tube is preloaded onto the dilator. Once the guidewire is in the airway, the cricothyroidotomy tube is passed over the dilator onto the wire and into the airway through the cricothyroid membrane. **(b, c)** Once the cricothyroidotomy tube is in place, the dilator and guidewire are removed together. The tube is secured as described for open cricothyroidotomy. **(d)** Insertion of the airway cannula in a caudal direction. Appropriate location of the airway cannula is ensured with end-tidal CO₂.

- The tracheostomy cuff is inflated with 10 cm³ of air and placement in the airway is confirmed using a CO₂ return and chest auscultation. Secure the tube to the skin.

Tips and Pitfalls

- A cricothyroidotomy may be a difficult procedure in patients with a short and thick neck or in the presence of a large neck hematoma. Knowledge of laryngeal anatomy and strategies to rapidly identify surface landmarks, such as the four-finger technique, are critical.
- Do not hesitate to make a larger skin incision, especially if the patient is obese or the anatomy is unclear. A small skin incision may hinder identification of the cricothyroid membrane or the introduction of the tube through the cricothyroidotomy.
- A vertical skin incision is preferred over a transverse incision in order to avoid injury to the anterior jugular veins. The incision in the cricothyroid membrane should be made in a transverse orientation.
- The skin incision should be centered over the cricothyroid membrane. A skin incision made too low will expose the thyroid isthmus, which can result in injury and/or bleeding. An incision made too high may result in entry into the thyrohyoid space mistakenly, or can damage the vocal cords.
- Passage of the tube into the subcutaneous tissues instead of the airway can be a catastrophic complication. To avoid this, place a tracheal hook under the cricoid cartilage and immobilize the trachea by retracting upwards and towards the patient's neck. This allows the insertion of the Bougie into the airway under direct visualization.
- Posterior airway perforation may occur in difficult procedures, when the scalpel is plunged deep into the airway or if the Bougie or dilator are inserted with an anteroposterior direction, instead of a direction downwards towards the carina.

Thoracostomy Tube Insertion

Demetrios Demetriades and Caroline Park

General Principles

- Strict antiseptic precautions and personal protective equipment should be used during the procedure. A single dose of prophylactic antibiotics with Cefazolin should be administered before the procedure. There is no need for further prophylaxis.
- Chest tubes can be inserted with an open or percutaneous dilational technique.
- The site of insertion is the same for open or percutaneous insertion and for hemothorax or pneumothorax, at the

fourth or fifth intercostal space, at the level of the nipple in males.

- Autotransfusion should be considered in all cases with large hemothoraces.

Positioning

The patient should be placed in the supine position with the arm abducted at 90° and elbow fully extended or flexed at 90° cephalad (Figures 3.1a and 3.1b). Adduction and internal rotation of the arm is a suboptimal position and should not be used (Figures 3.1c and 3.1d).

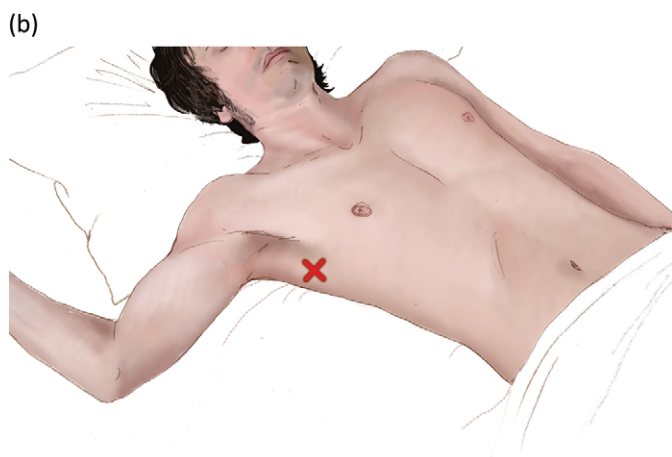
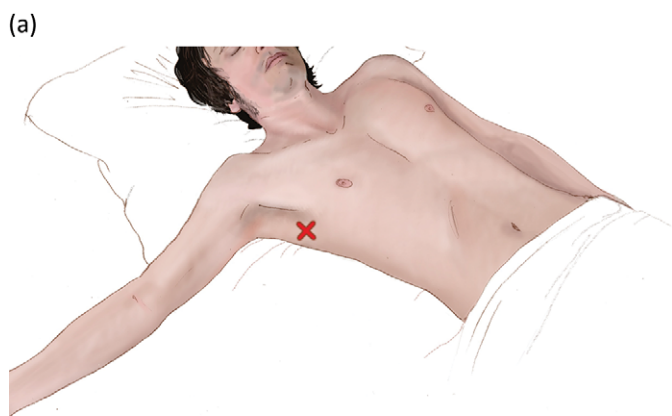
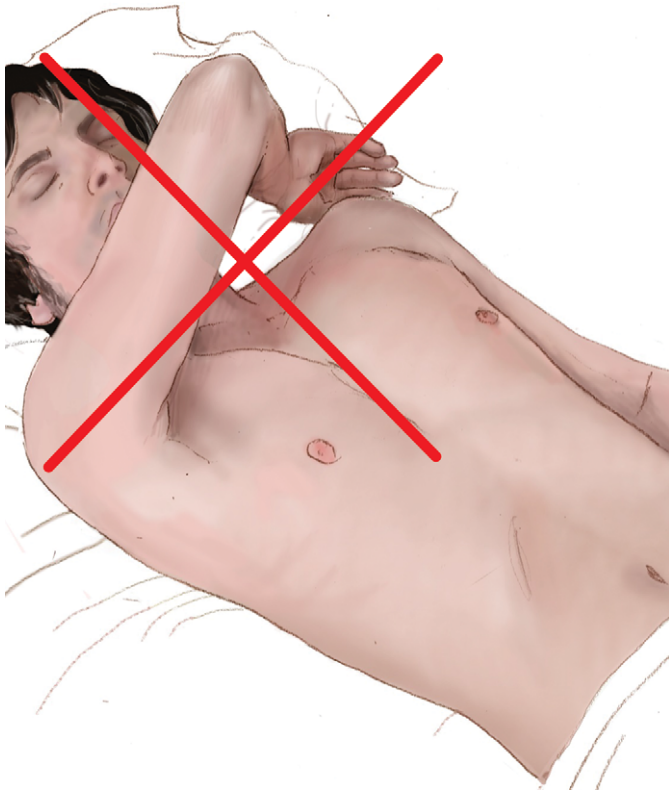


Figure 3.1 The patient should be placed in the supine position with the arm abducted at 90° and elbow fully extended (a) or flexed cephalad at 90° (b). Adduction and internal rotation of the arm is a suboptimal position and should not be used (c). The insertion site should be in the fourth or fifth intercostal space at the midaxillary line, at or slightly above the nipple level (d).

(c)



(d)

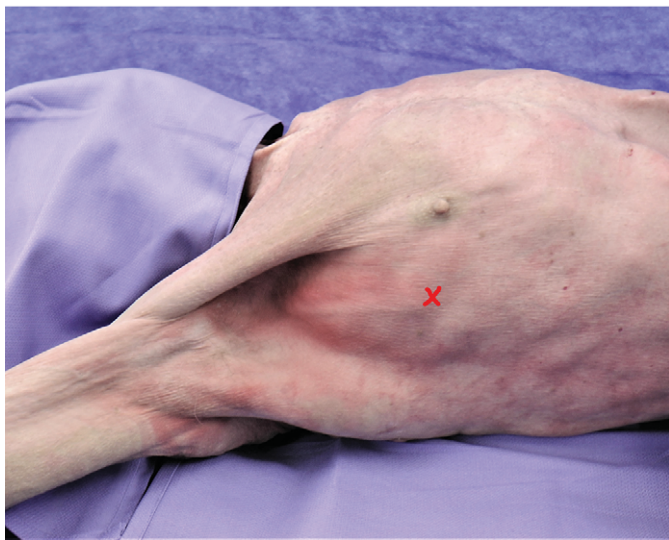


Figure 3.1 (cont.)

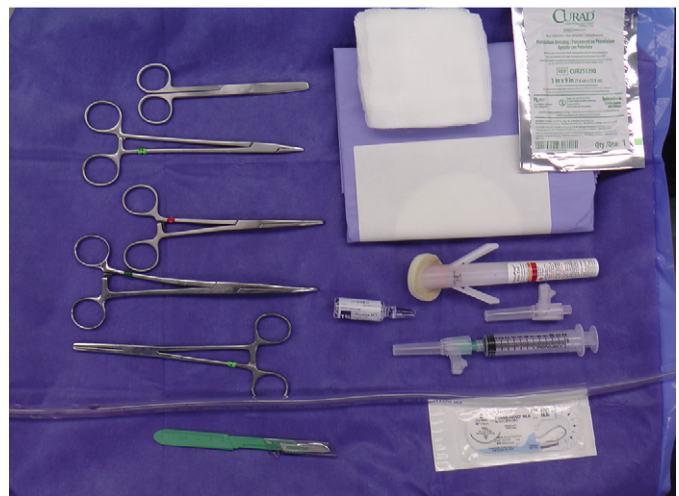
Site of Tube Insertion

- Fourth or fifth intercostal space, midaxillary line. The external landmark is at or slightly above the nipple level in males. Insertion at this site is optimal due to the relatively thin chest wall and distance from the diaphragm, which during expiration can easily reach the sixth intercostal space.

Open Technique

- Usual thoracostomy tube sizes for adults are 28–32 Fr. There is no advantage to using larger tubes. For pediatric cases, refer to the Broselow tape (Figures 3.2a and 3.2b).
- After local anesthetic is injected in the skin, soft tissue, and along the periosteum, a 1.5–2.0 cm incision is made through the skin and subcutaneous fat (Figure 3.3).

(a)



(b)



Figure 3.2 Thoracostomy tube insertion tray (a). The tube is grasped with a clamp through its distal fenestration. The distal end of the tube (left) is clamped to avoid splashing of blood (b).



Figure 3.3 A 1.5–2.0 cm incision is made through the skin and subcutaneous fat, in the fourth or fifth intercostal space at the midaxillary.

- A Kelly forceps is used to enter the pleural cavity. Dissection should be kept close to the upper edge of the rib to avoid injury to the intercostal vessels. The Kelly forceps is inserted into the pleural cavity in a controlled manner to avoid injury to the intrathoracic organs (Figures 3.4a and 3.4b).

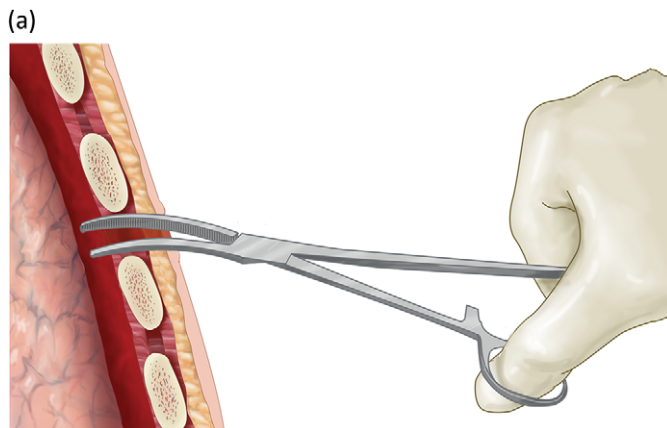


Figure 3.4 a-b: Kelly forceps are used to enter the pleural cavity just over the top of the rib. Spreading of the subcutaneous fat and tissue as the Kelly is withdrawn from the pleural cavity.

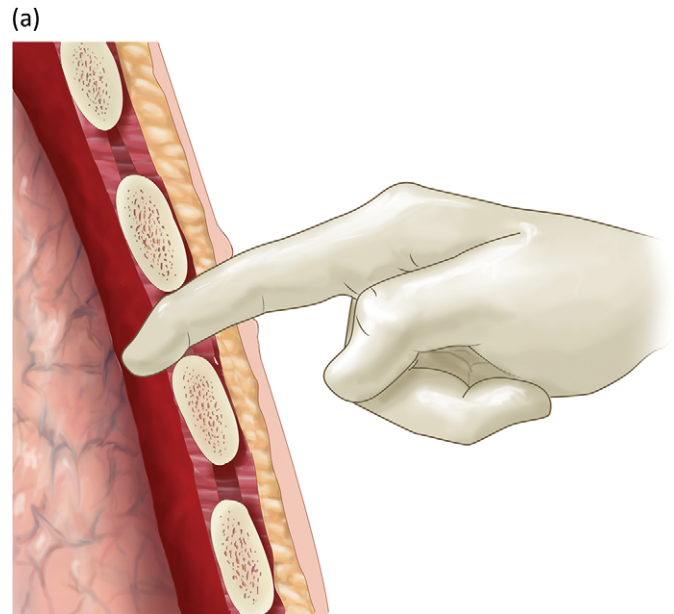


Figure 3.5 (a, b) Digital exploration of the pleural cavity to rule out adhesions.

- There is no need for subcutaneous tunneling, as it is painful and does not reduce the risk of empyema or air leak.
- A finger should be inserted into the pleural cavity and swept 360° to evaluate for adhesions and avoid intrapulmonary placement of the tube (Figures 3.5a and 3.5b).
- The tube is grasped with a clamp through its distal fenestration. The distal end of the tube is clamped to avoid uncontrolled drainage of blood. The tube is firmly inserted into the pleural cavity (Figures 3.6a and 3.6b). As soon as it enters the cavity, the clamp is released and withdrawn, while the tube is advanced in a twisting fashion towards the apex of the hemithorax and posteriorly. Make sure that all of the tube fenestrations are in the pleural cavity. In an adult patient, the tube should be inserted to 8–10 cm (Figures 3.6c and 3.6d).
- When the tube is in place, it should be rotated 360° to prevent inappropriate kinking. If the tube does not rotate freely, it should be pulled back slightly and rotated again.

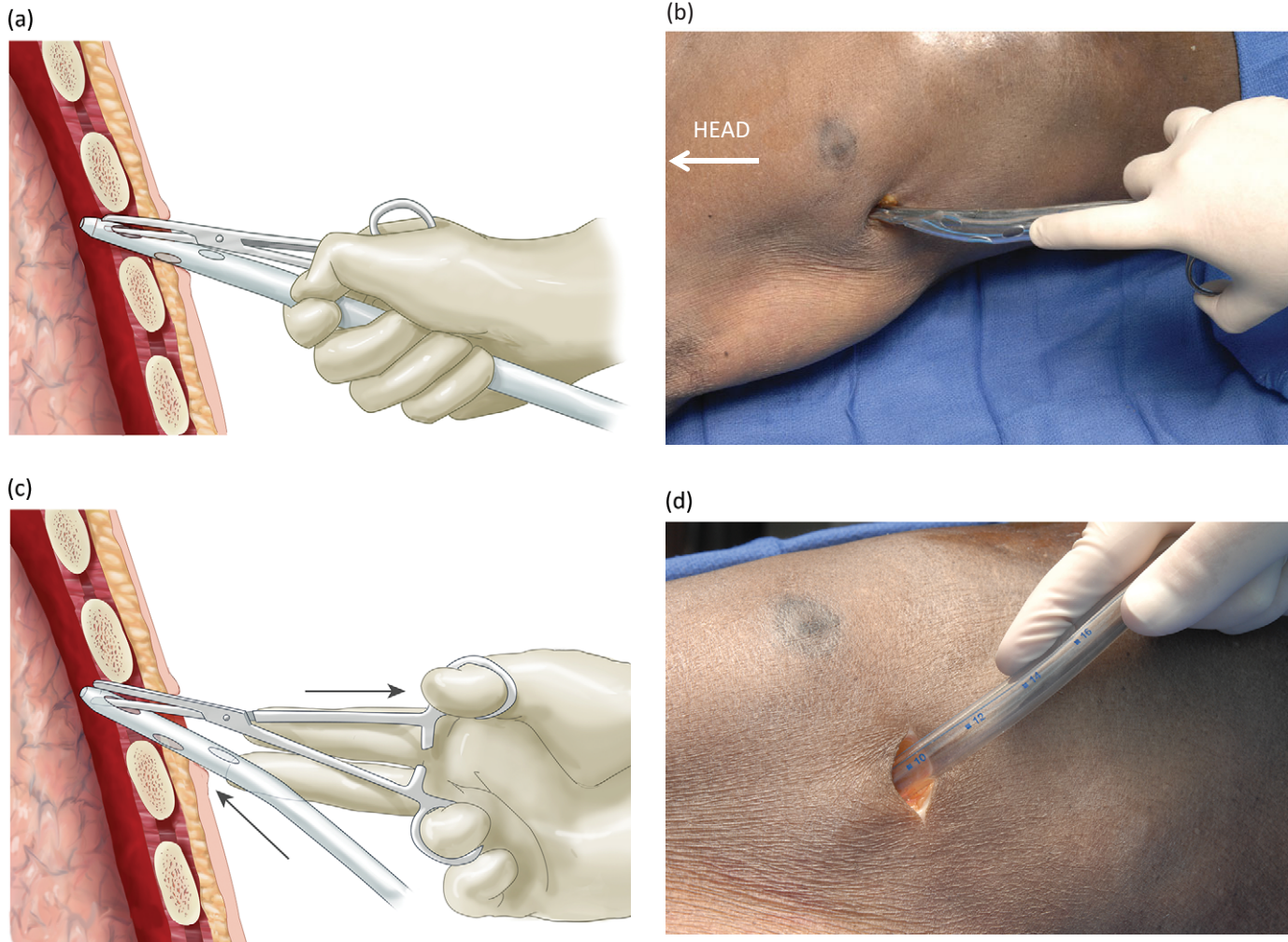


Figure 3.6 (a, b) The tube is grasped with a Kelly clamp through its distal fenestration and is firmly forced into the pleural cavity. (c) When the tip of the tube enters the cavity, the clamp is released and withdrawn, while the tube is advanced in a twisting fashion towards the apex and posteriorly. (d) Chest drain in place (in normal-weight adults, no more than 8–10 cm of the drain should be inserted into the chest).

- Connect tube to an underwater chest drainage collection system and apply wall suction at -20 cm H_2O . Encourage the patient to cough while sitting up, lying on their back and sides in order to promote blood drainage and lung reexpansion.
- Secure tube in place with 0 Silk suture. If the incision at the insertion site is too long, it should be closed around

the tube with interrupted sutures. A horizontal mattress suture may be placed around the tube and left untied to be used for wound closure at the time of tube removal. The tube is further secured to the thoracic wall with adhesive tape (Figures 3.7a through 3.7d).

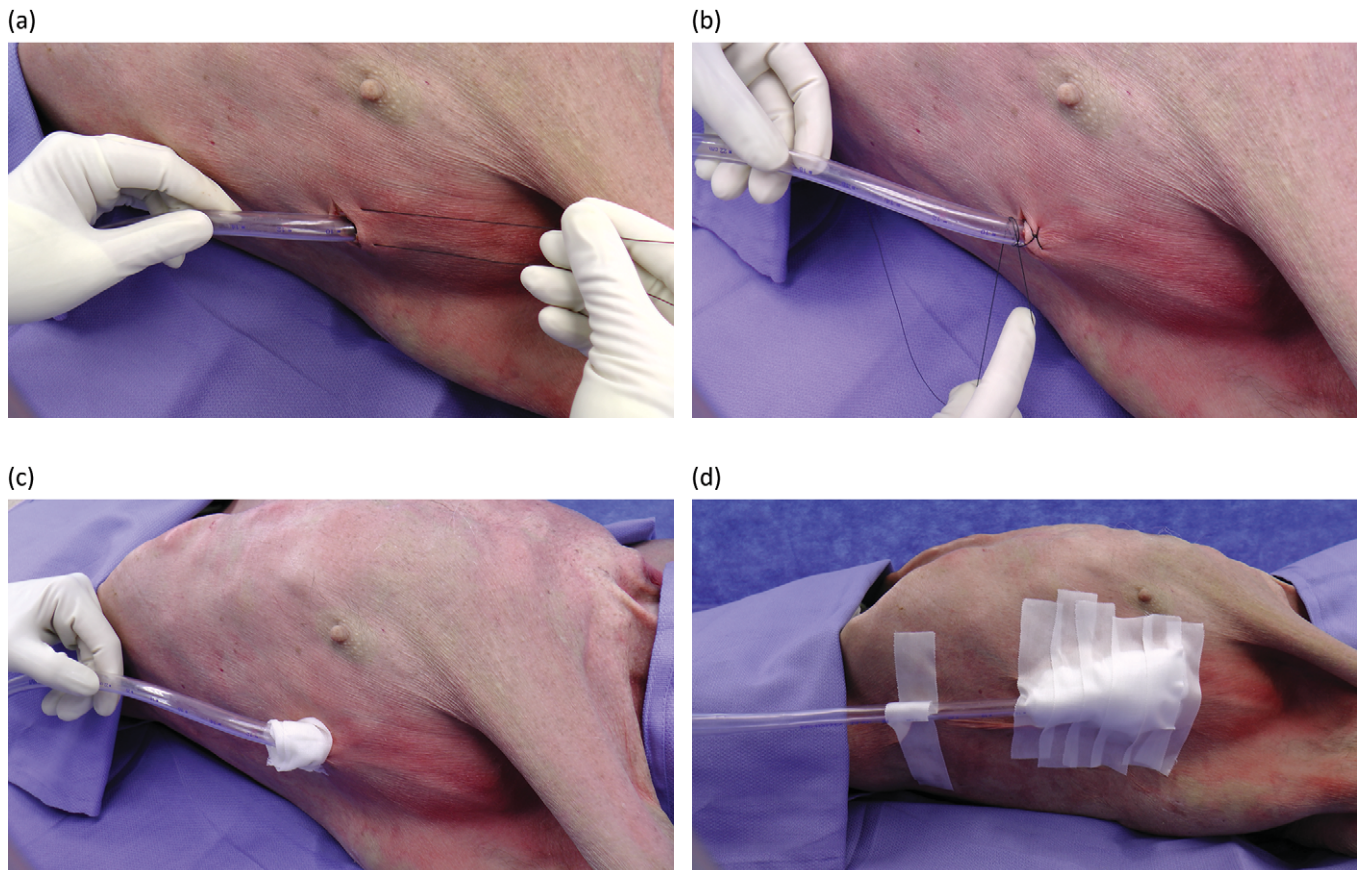


Figure 3.7 (a–d) The tube is secured in place with 0 Silk suture. A horizontal mattress suture may be placed around the tube and left untied to be used for wound closure at the time of tube removal. The tube is further secured to the thoracic wall with adhesive tape.



Figure 3.8 A percutaneous chest tube tray.

Percutaneous Technique

- Less painful than the open technique.
- After infiltrating the area with local anesthetic, an introducer needle attached to a syringe with sterile saline is inserted into the chest cavity. Insert close to the upper border of the rib to avoid injury to the intercostal vessels, which are located at the inferior border of the rib. Aim slightly posterior and towards the apex of the lung. Entry into the pleural cavity is confirmed by aspiration of blood or air bubbles (Figures 3.9 and 3.10).
- Insert the guidewire through the needle. Remove the needle while keeping the guidewire in place. Make a skin incision over the needle that is slightly larger than the diameter of the chest tube. Remove needle (Figures 3.11 and 3.12).
- Insert the dilator over the guidewire.
- Remove dilator and insert the chest tube (8–10 cm) over the guidewire (Figures 3.13 and 3.14).
- Remove the guidewire, connect to the collection system, and secure the tube on the skin.
- Obtain chest X-ray.

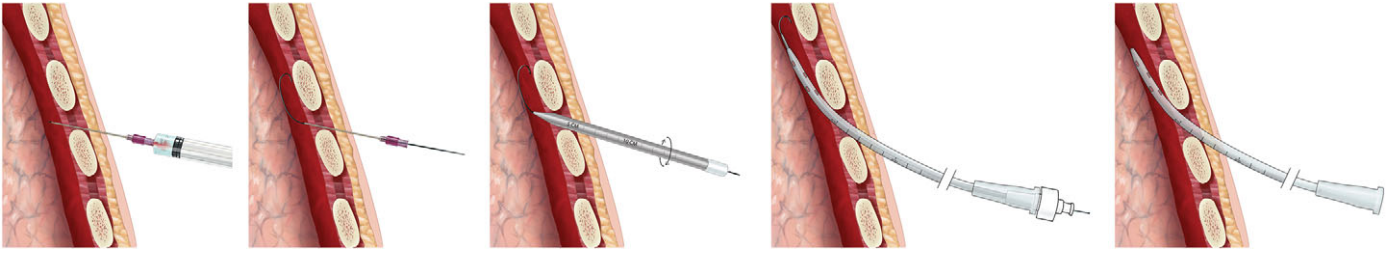


Figure 3.9 The percutaneous dilational insertion of chest tube utilizes the Seldinger guidewire technique with progressive dilation.

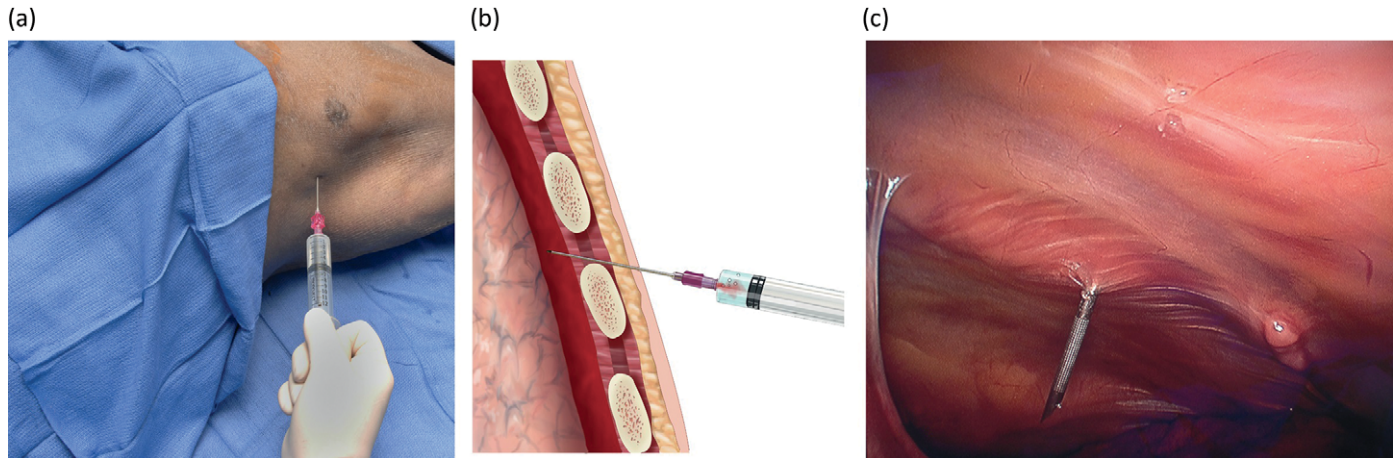


Figure 3.10 The step-by-step insertion of a percutaneous chest tube by the dilational technique: photograph of the external portion of procedure (a), illustration (b), thoracoscopic view (c). The introducer needle with a syringe with saline is used to confirm entrance into the thorax with the return of blood or air bubbles. It is inserted in the fourth or fifth intercostal space, just above the rib to avoid injury to the neurovascular bundle.

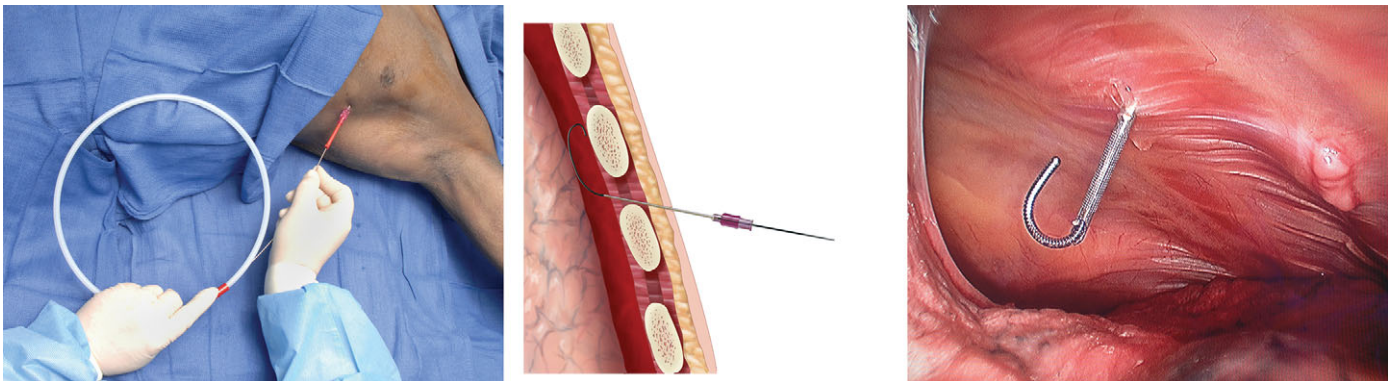


Figure 3.11 A guidewire is inserted through the introducer needle and the needle removed.

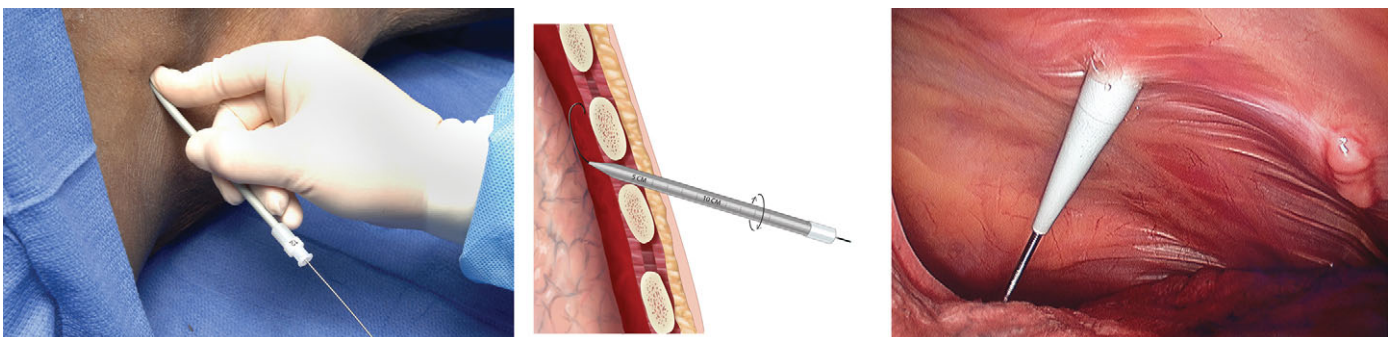


Figure 3.12 Using the Seldinger technique, the tract is sequentially dilated after making a small skin incision for the tube.

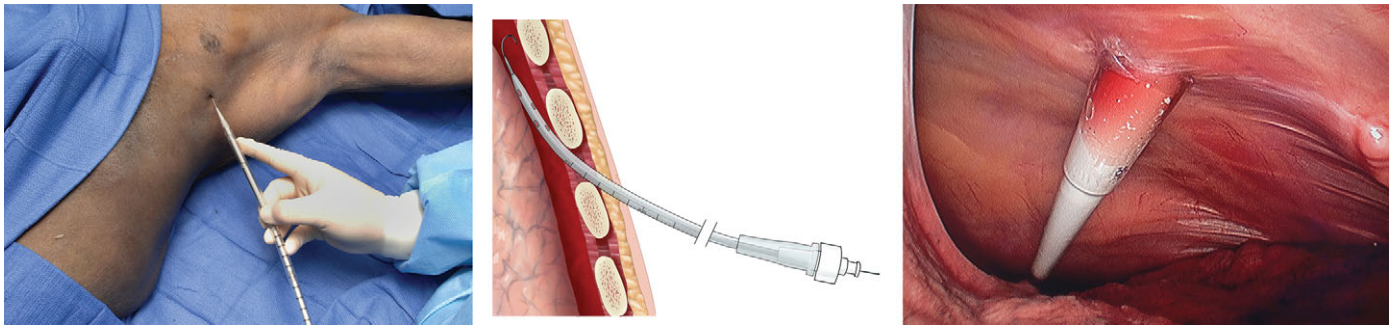


Figure 3.13 The tube is passed into the thoracic cavity over the guidewire.

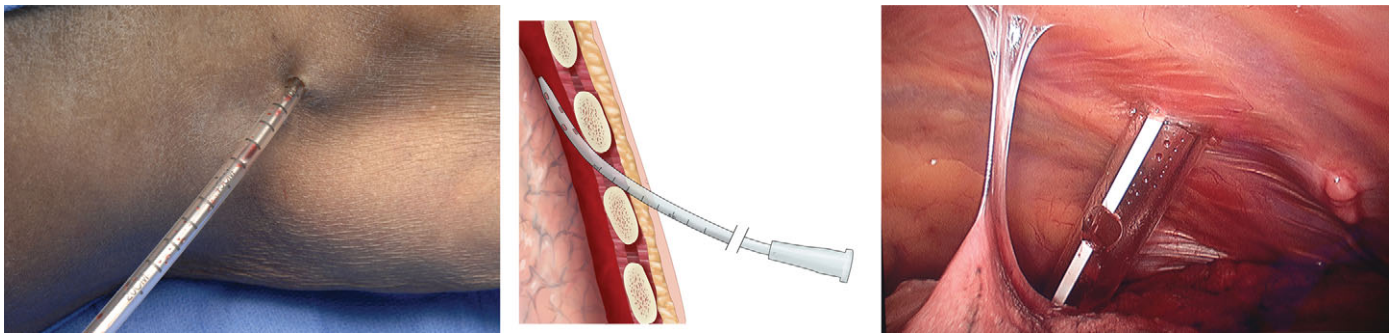


Figure 3.14 Final position of the tube after removal of the guidewire.

Removal of the Chest Tube

- The chest tube can be removed as soon as possible, once there is no air leak and the output is minimal. The duration of the chest tube is an independent risk factor for empyema.
- The tube can be safely removed in deep inspiration or expiration.

Autotransfusion

- Blood autotransfusion is fast, inexpensive relative to banked blood product, and simple. It provides the patient with safe, matched, warm blood with coagulant factors. There are numerous autotransfusion systems available commercially.
- It is recommended for use in all patients with chest trauma, both blunt and penetrating, with large hemothoraces.
- Anticoagulant, citrate 1 mL per 10 mL of blood, can be used, but is not absolutely necessary. It should be added to the collection chamber prior to collection.

Tips and Pitfalls

- Technical complications include bleeding secondary to injury of the intercostal vessels, the lung, heart, diaphragm, liver, or spleen. Insertion of the tube with the use of a

trocars is associated with an increased risk of injury. Digital exploration of the pleura to rule out adhesions reduces the risk of lung injury.

- Iatrogenic injuries to the diaphragm, liver, or the spleen may occur if the tube is placed too low. Avoid this serious complication by staying at or above the fourth or fifth intercostal space.
- Tube misplacement is another common complication. Insertion of the tube too far into the pleural cavity may result in kinking and poor drainage. In a normal habitus adult patient, do not insert the tube beyond 8–10 cm. Misplacement of the tube into the subcutaneous tissues is another technical complication, especially in obese patients.
- Persistent air leaks can be due to technical problems or the injury itself. Make sure that all of the tube perforations are located within the chest cavity and that the incision around the tube is tightly sealed. All connections should be taped. If there are no technical problems, the differential diagnosis should include tracheobronchial injury or bronchopleural fistula.
- Larger size tubes do not drain more effectively. They can be more painful and more difficult to insert. In adults, do not exceed size 28–32 Fr. For pneumothoraces, use smaller size drains.

Emergency Room Resuscitative Thoracotomy

Demetrios Demetriades, James Bardes, and Scott Zakaluzny

Surgical Anatomy

- The major muscles that are divided during resuscitative thoracotomy include the pectoralis major, the pectoralis minor, and the serratus anterior muscles.
 - Pectoralis major muscle: It originates from the anterior surface of the medial half of the clavicle, the anterior surface of the sternum, and the cartilages of all of the true ribs (the first seven ribs which are directly attached to the sternum). The 5-cm wide tendon inserts into the upper humerus.
 - Pectoralis minor muscle: It arises from the third, fourth, and fifth ribs, near their cartilages, and inserts into the coracoid process of the scapula.
 - Serratus anterior muscle: It originates from the first eight or nine ribs and inserts into the medial part of the scapula.

- The left phrenic nerve descends on the lateral surface of the pericardium.
- The lower thoracic aorta is situated to the left of the vertebral column. The esophagus descends on the right side of the aorta to the level of the diaphragm, where it moves anterior and to the left of the aorta. The aorta is the first structure felt while sliding your fingers along the left posterior wall anterior to the spine.

General Principles

- External cardiac compressions can produce approximately 20% of the baseline cardiac output and tissue perfusion. Open cardiac massage can produce approximately 55% of the baseline cardiac output. In traumatic cardiac arrest, external cardiac compression has little or no role, especially in the presence of cardiac tamponade or an empty heart due to severe blood loss.

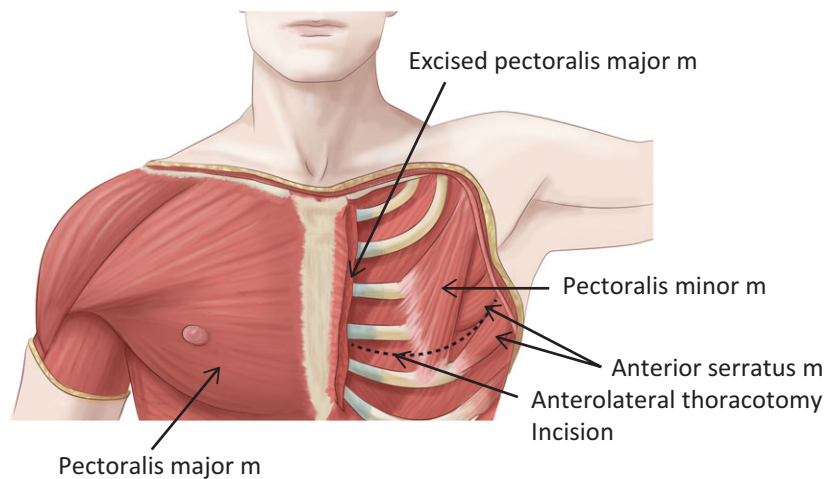


Figure 4.1 The resuscitative thoracotomy incision is placed just below the nipple in males or in the inframammary crease in females (fourth to fifth intercostal space). The major muscles divided include the pectoralis major, pectoralis minor, and the serratus anterior.

- Trauma patients arriving in the emergency room in cardiac arrest, or imminent cardiac arrest, are candidates for resuscitative thoracotomy. The indications and contraindications are controversial, with many surgeons supporting strict criteria and others supporting liberal criteria for the procedure. Those supporting strict criteria cite the futility of the operation and the risks to staff. Those practicing liberal criteria, including the USC trauma program, cite those that do survive, the opportunity for organ donation, and the educational value of the procedure.
- The emergency room resuscitative thoracotomy allows release of cardiac tamponade, control of bleeding, direct cardiac massage and defibrillation, aortic cross-clamping, and management of air embolism.
- Endotracheal intubation, intravenous line placement, and resuscitative thoracotomy can be performed simultaneously. The endotracheal tube may be advanced into the right bronchus in order to collapse the left lung and make the procedure easier. However, this may cause oxygenation problems in the presence of injuries to the right lung.

Special Surgical Instruments

The resuscitative thoracotomy tray should be kept simple and include only a few absolutely essential instruments, which include a scalpel, Finochietto retractor, two Duval lung forceps, two vascular clamps, one long Russian forceps, four hemostats, one bone cutter, and one pair of long scissors. In addition, good lighting, working suction, and an internal defibrillator should be ready before patient arrival. All staff should wear personal protective equipment.



Figure 4.2 The emergency room resuscitative thoracotomy tray should include only the absolutely essential instruments (scalpel, Finochietto retractor, two Duval lung forceps, two vascular clamps, one long Russian forceps, four hemostats, one bone cutter, and long scissors).

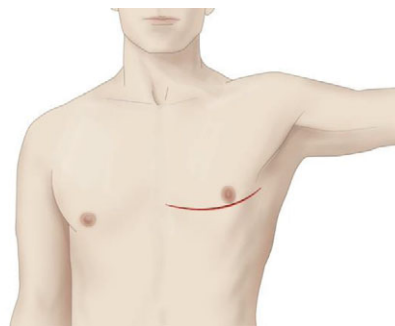
Positioning

Supine position with the left arm abducted at 90° or above the head. Antiseptic skin preparation may be performed; however, rapid entry with release of tamponade and control of hemorrhage trumps sterility, and should take precedence over meticulous antiseptic precautions. Draping is not required, as it is time-consuming.

Incision

- The left anterolateral incision is the standard incision for resuscitative thoracotomy. It does not need special patient positioning, provides good exposure to the heart and the left lung, and allows cross-clamping of the thoracic aorta. If necessary, it can be extended as a clamshell incision into the right chest through a mirror incision and division of the sternum.
- The incision is performed through the fourth to fifth intercostal space, at the nipple line in males or inframammary fold in females. It starts at the left parasternal border and ends at the posterior axillary line. Follow the curve of the ribs by aiming towards the axilla. The pectoralis major and pectoralis minor are encountered and divided in the anterior part of the incision, and the serratus anterior in the posterior part of the incision.

(a)



(b)



Figure 4.3 (a, b) The resuscitative thoracotomy incision is placed just below the nipple in males or in the inframammary crease in females (through the fourth to fifth intercostal space). It starts at the left parasternal border and extends to the midaxillary line, with a direction towards the axilla.

- The intercostal muscles are divided close to the superior border of the rib, in order to avoid the neurovascular bundle, and the pleural cavity is entered with the use of scissors, taking care to avoid injury to the underlying inflated lung. Right mainstem intubation or holding ventilation during entry into the pleural cavity can

reduce the risk of lung injury. A Finochietto retractor is then inserted and the ribs are spread. The left lower lobe of the lung is grasped with Duval forceps and retracted towards the patient's head and laterally to improve the exposure of the heart and the thoracic aorta.

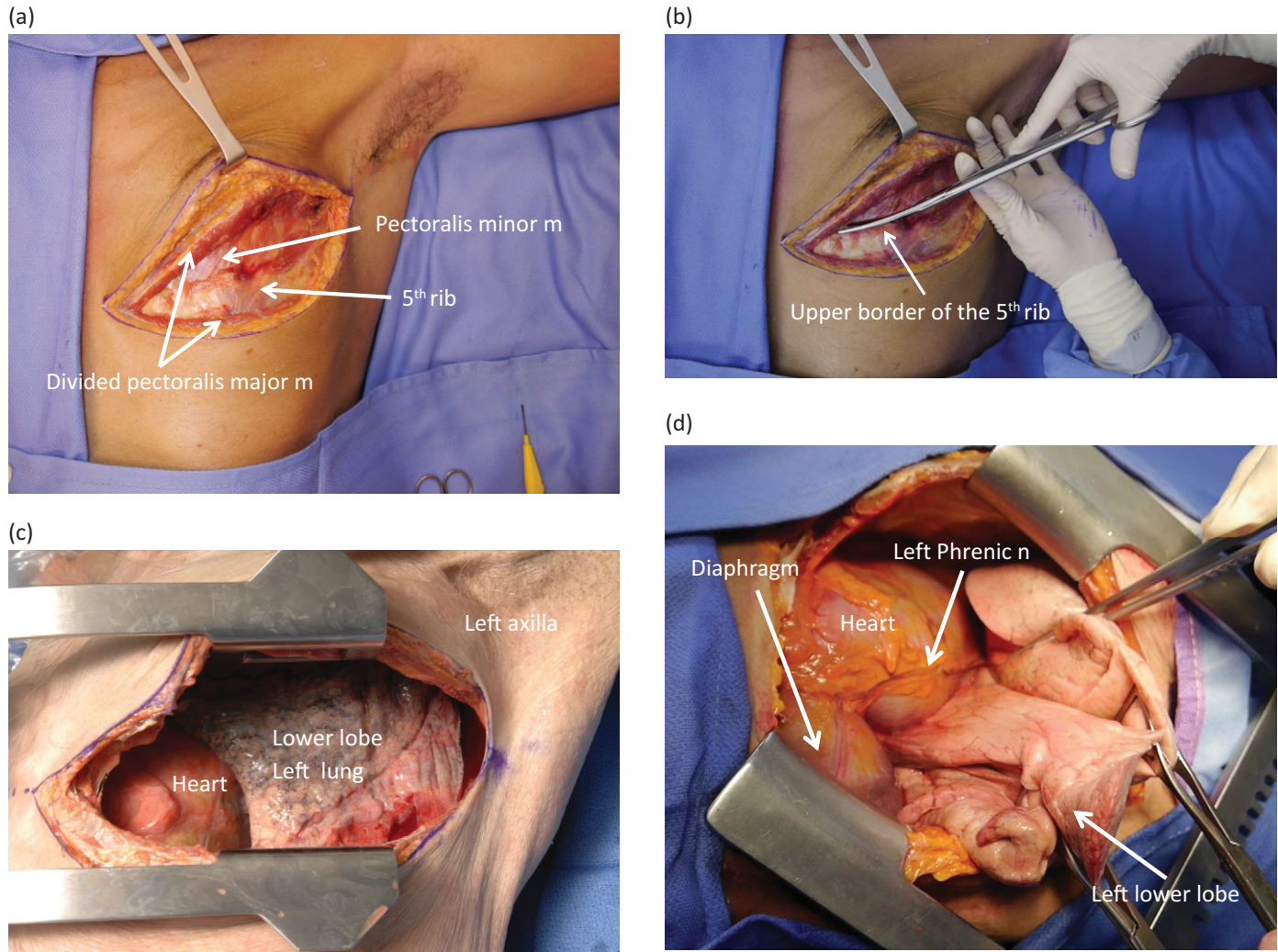


Figure 4.4 (a) Division of the pectoralis major and the underlying pectoralis minor muscles. (b) The intercostal muscles are divided at the superior border of the rib with scissors, taking care to avoid injury to the lung. (c) The pleural cavity is entered and a Finochietto retractor is placed and the left lung and the heart are exposed. (d) The left lower lobe of the lung is grasped with Duval forceps and retracted towards the patient's head and laterally to improve the exposure of the heart and the thoracic aorta.

- In some patients with injuries to the right chest or the upper mediastinal vessels, a clamshell incision may be needed for bleeding control and improved exposure. The left thoracotomy incision is extended through a transverse division of the sternum with a bone cutter or heavy scissors into a symmetrical right thoracotomy. During the division of the sternum, both internal mammary arteries are transected, and clamping or ligation should be performed after restoration of cardiac activity and circulation.

(a)



(b)

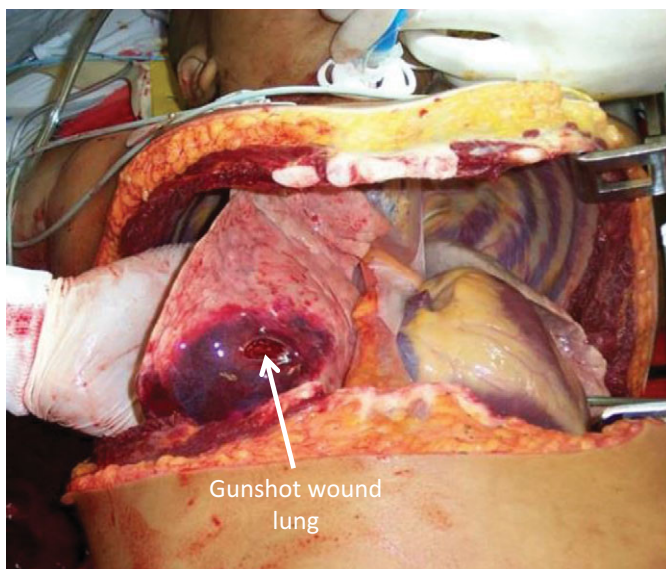


Figure 4.5 (a, b) Clamshell incision: The left thoracotomy incision is extended through a transverse division of the sternum into a symmetrical right thoracotomy. It provides good exposure of the anterior aspect of the heart, the superior mediastinal vessels, and both lungs.

Procedure

- After entering the left pleural cavity, any free blood is evacuated and any obvious significant bleeding from the lung or thoracic vessels are controlled, initially by direct pressure, and subsequently with a vascular clamp.
- The next step is to open the pericardium to release any tamponade, repair any cardiac injury, and perform direct cardiac resuscitation with cardiac massage, defibrillation, and the intracardiac injection of medication.
- The left phrenic nerve is identified along the lateral surface of the pericardium. In the absence of cardiac tamponade, the pericardium is grasped with two hemostats anterior to the nerve and a small incision is made. However, in the presence of tamponade, the pericardium is tense and it may be difficult to apply a hemostat. In these cases, a small pericardiotomy is performed with a scalpel and the pericardium is then opened longitudinally and parallel to the phrenic nerve.

(a)

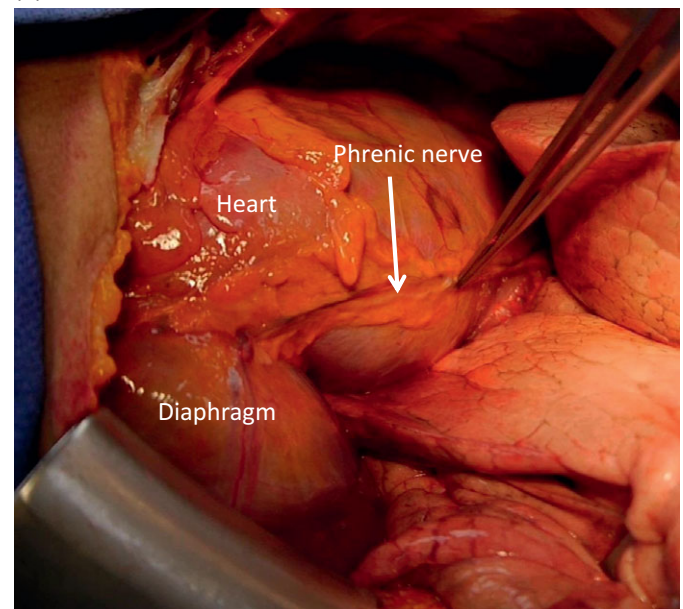
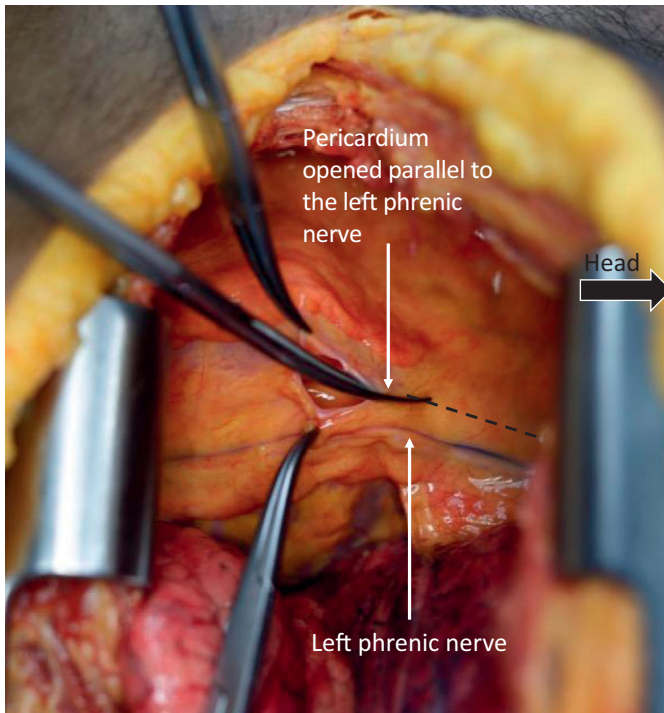


Figure 4.6 (a) The phrenic nerve is seen on the lateral border of the pericardium and should be protected. The pericardium is opened in front and parallel to the nerve.

(b)



(c)

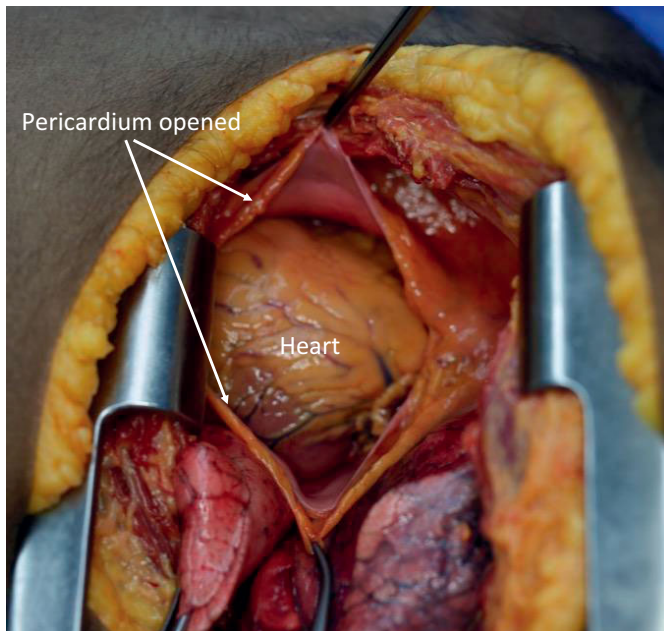


Figure 4.6 (cont.) (b) The pericardium is open in front and parallel to the phrenic nerve. (c) After opening the pericardium, the heart can easily be evaluated.

- Any tamponade is then released and cardiac bleeding is controlled by finger compression between the thumb and index finger, or for large atrial injuries, with a vascular clamp. For small cardiac wounds, temporary bleeding control may be achieved by inserting and inflating a Foley catheter. Care should be taken to avoid accidental dislodgement of the balloon and inadvertent puncture of the balloon during suturing. Avoid excessive pressure or traction on the Foley catheter, as this can enlarge the laceration. Skin staples may be used temporarily for stab wounds, but will be ineffective in most cases of gunshot wounds because of the associated cardiac tissue loss.

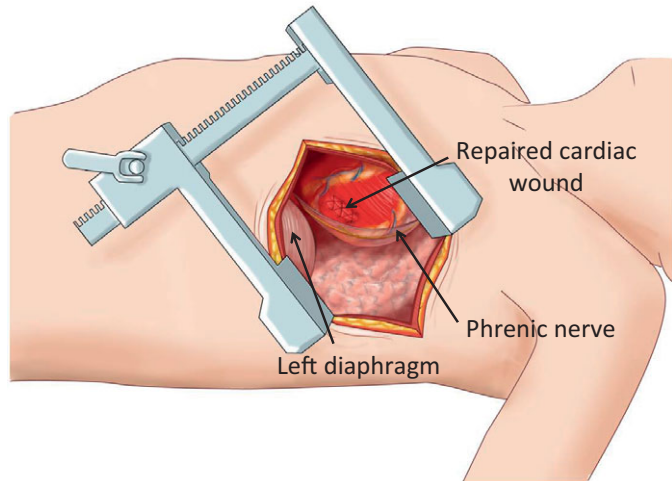


Figure 4.7 The cardiac wound is repaired with figure-of-eight, or horizontal mattress sutures, using nonabsorbable 2-0 or 3-0 suture on a large tapered needle.

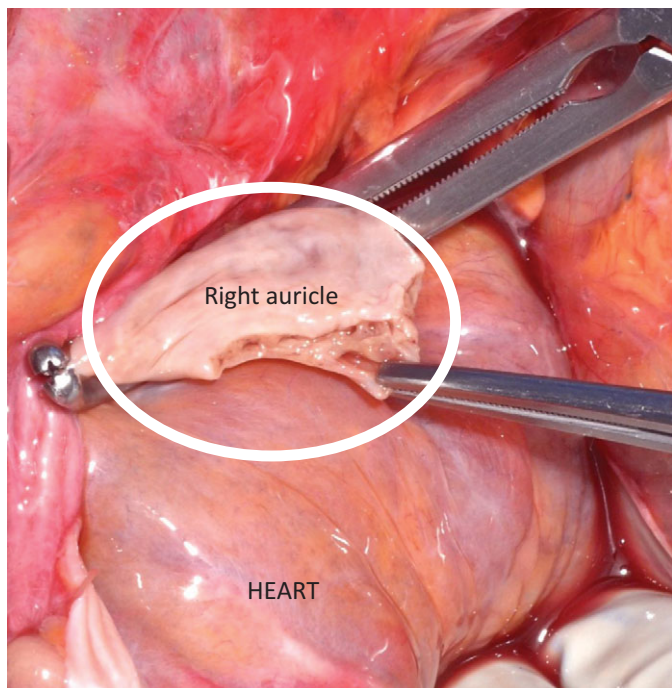
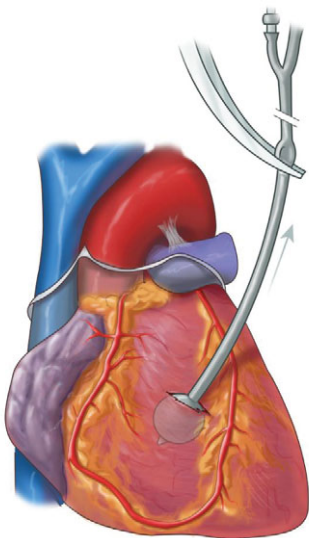


Figure 4.8 Bleeding from atrial injuries can temporarily be controlled with a vascular clamp.

(a)



(b)

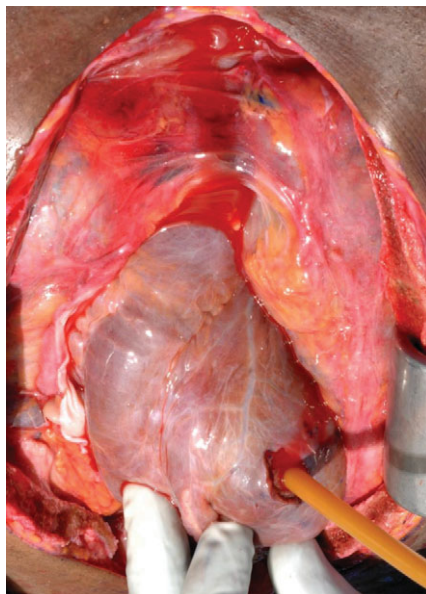
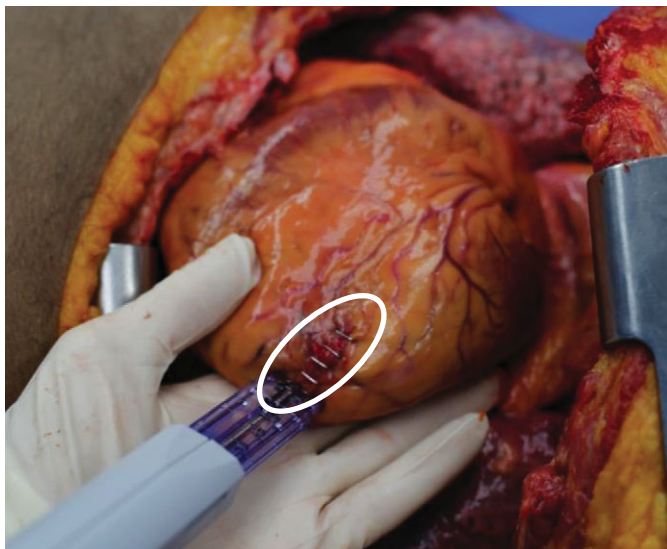


Figure 4.9 (a, b) In some cases with small cardiac wounds, temporary bleeding control may be achieved by inserting and inflating a Foley catheter. Avoid excess traction on the Foley catheter, as this can enlarge the laceration.

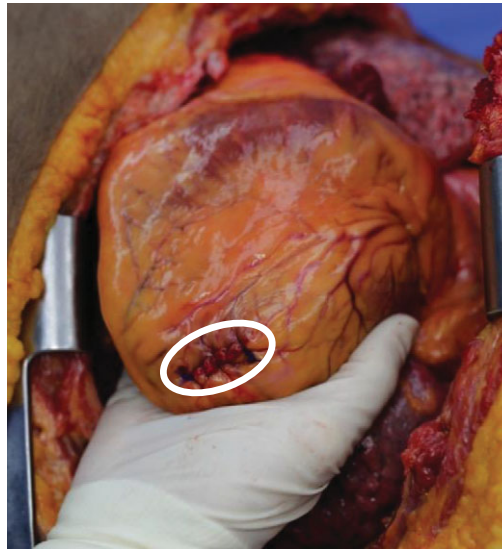
- The cardiac wound is repaired with figure-of-eight, or horizontal mattress, or continuous sutures, using nonabsorbable 2-0 or 3-0 suture on a large tapered needle. Routine use of pledgets is time-consuming and

unnecessary in the majority of cases, and should be reserved only in cases where the myocardium tears while tying the sutures. The technical details of cardiac repair are demonstrated in [Chapter 15 Cardiac Injuries](#).

(a)



(b)



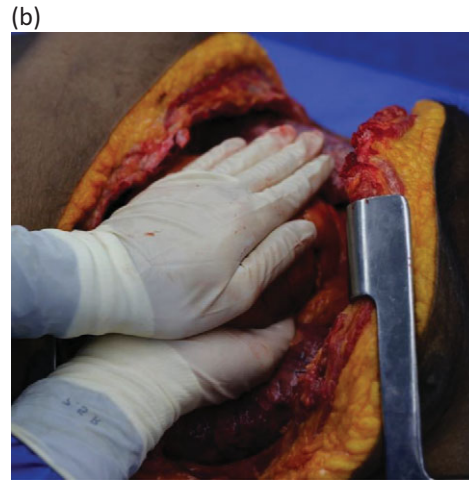
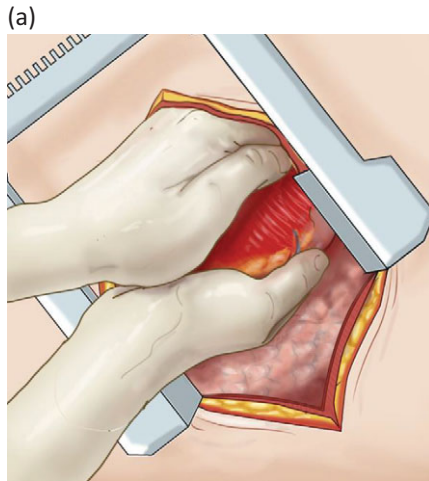
Repaired
cardiac
laceration

Figure 4.10 (a) A skin stapler can be used for temporary closure of cardiac stab wounds. **(b)** The cardiac wound is definitively repaired with figure-of-eight or horizontal mattress, using nonabsorbable 2-0 or 3-0 suture.

Open Cardiac Massage

Cardiac massage should always be performed using both hands. Squeezing the heart with only one hand is less effective and may result in rupture of the heart with the thumb. The heart should be held between the two palms and compression should proceed from the apex towards the base.

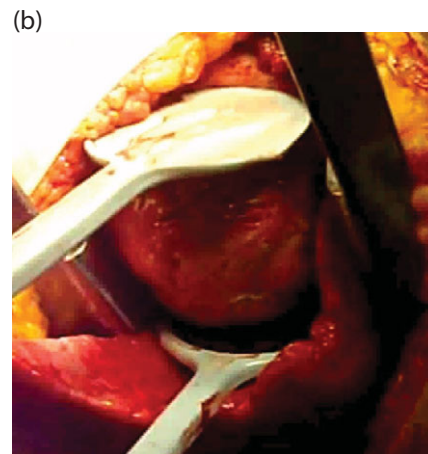
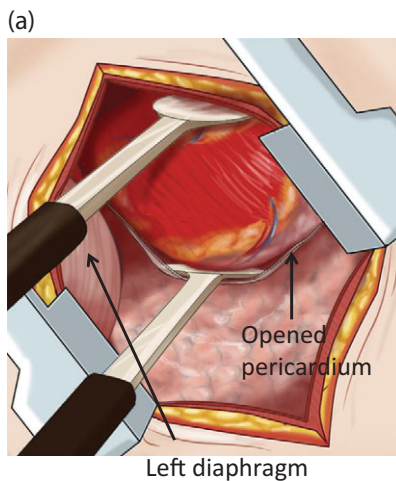
Figure 4.11 (a, b) Technique of internal cardiac massage: The heart is held between the two palms, squeezing from the apex towards the base of the heart.



Internal Cardiac Defibrillation

Internal cardiac defibrillation should be used in cases with ventricular fibrillation or pulseless ventricular tachycardia. The two internal cardiac paddles are placed on the anterior and posterior wall of the heart and the heart is shocked with 10–50 joules.

Figure 4.12 (a, b) Internal defibrillation: The two internal cardiac paddles are placed on the anterior and posterior wall of the heart.



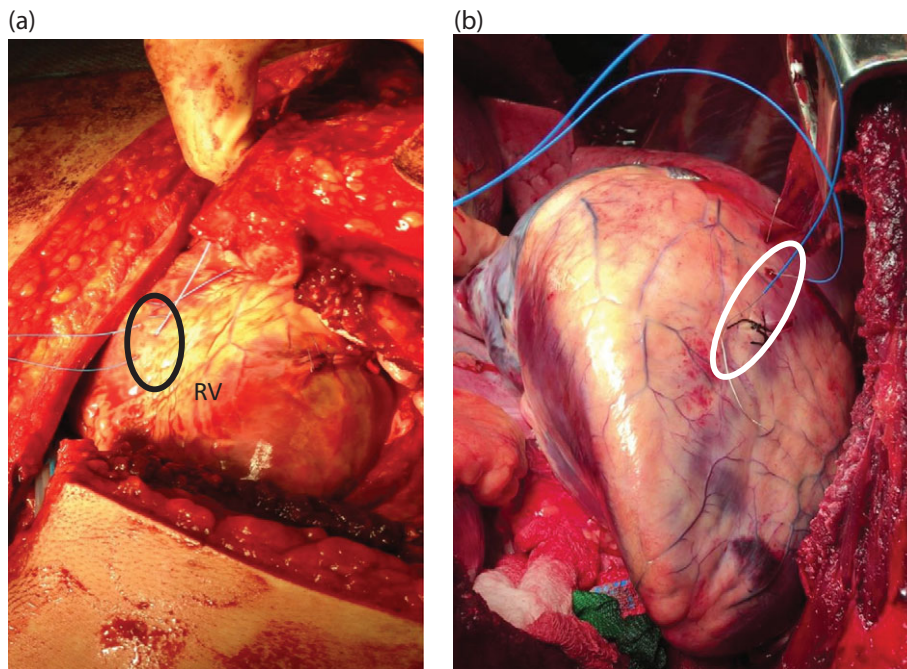


Figure 4.13 (a, b) The pacing wires are placed in the epicardium, on the upper part of the anterior wall of the right ventricle, about 1 cm apart below (circle).

Pharmacological Treatment of Cardiac Arrest

Medications such as epinephrine, calcium, magnesium, and sodium bicarbonate can be injected into the left ventricle as needed.

Epicardial Pacing

- Intraoperative and early postoperative temporary epicardial pacing should be considered in patients with arrhythmias, in order to improve hemodynamic function and suppress tachyarrhythmias.
- Epicardial pacing wires are usually placed on the upper part of the anterior wall of the right ventricle, one at the top of the ventricle and the second approximately 1 cm below. Alternatively, the wires can be placed on the left ventricle.
- Epicardial wires have a small needle on one end. This needle is used to embed the wires superficially in the myocardium, after which the needle is cut off. Some wires are slightly coiled to prevent easy dislodgement. A larger needle on the other end of the wire is used to pierce the chest wall and bring the wire to the skin surface. The exteriorized wires are then connected to the pacer. The usual settings for the pacer are a heart rate of 70–90 per minute and a maximal current output of 10 mA.

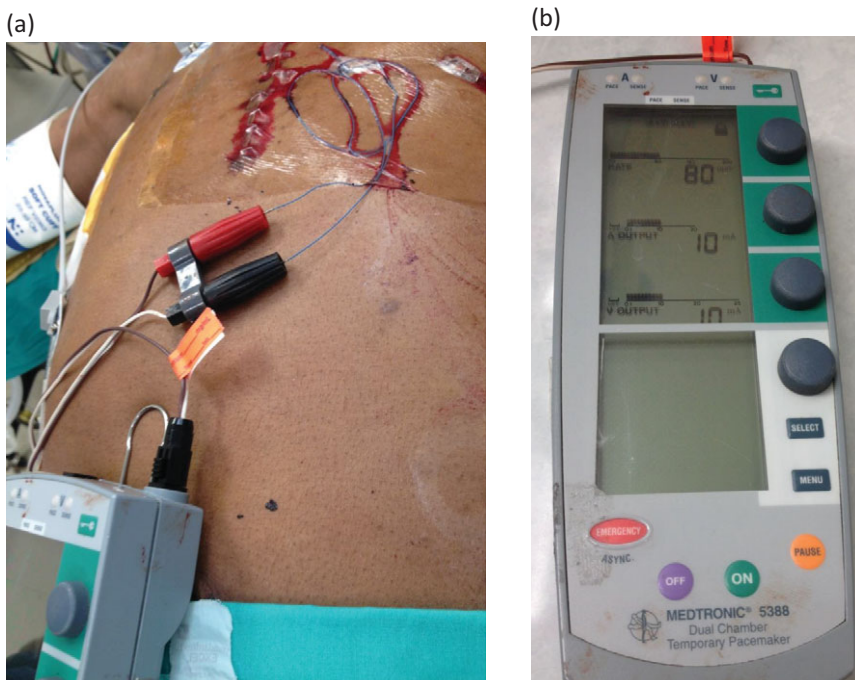


Figure 4.14 (a, b) External cardiac pacer. The usual settings of the pacer are: heart rate 70–90 per minute and V output 10 mA.

Aortic Cross-Clamping

The most accessible site of the thoracic aorta for cross-clamping is approximately 2–4 cm above the diaphragm. The left lower lobe of the lung is grasped and retracted upwards with a Duval clamp in order to improve the exposure of the aorta. In cardiac arrest, the aorta is collapsed and might be difficult to distinguish from the esophagus. The aorta is the

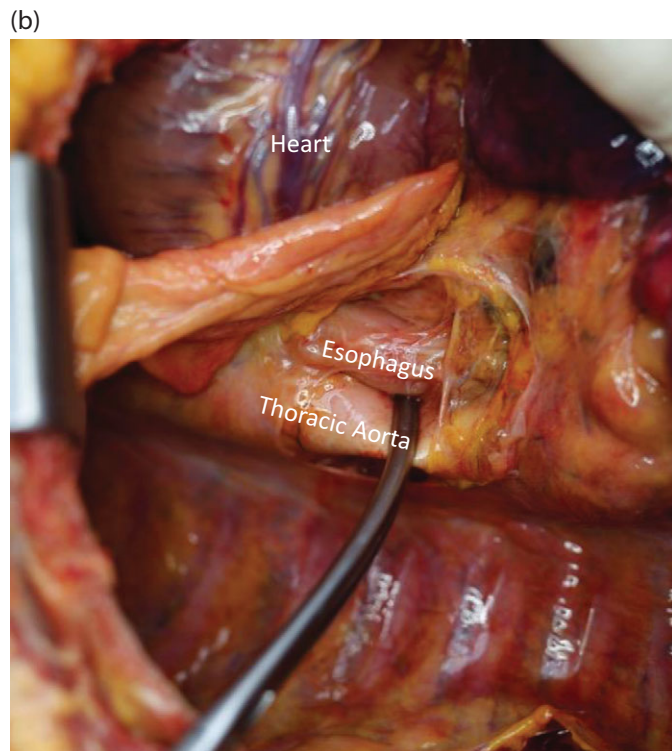
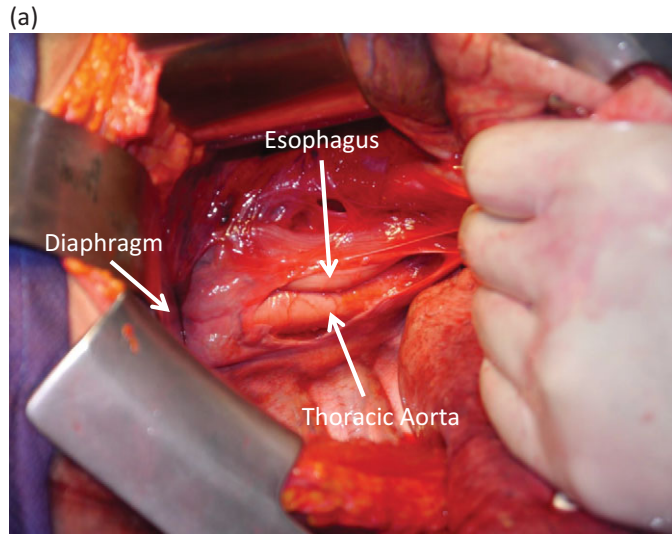


Figure 4.15 (a) Cross-clamping of the thoracic aorta. The mediastinal pleura over the aorta is incised. Note the esophagus anteriorly and medially. The esophagus may be mistaken for the aorta if there is no pulse and the aorta is collapsed. (b) Vascular clamp applied on the thoracic aorta.

first structure felt while sliding the fingers along the left posterior wall towards the spine. The esophagus is more anterior and medial. After intubation, an orogastric tube can be placed to assist with identification of the esophagus; however, this should not delay aortic cross-clamping. The inferior pulmonary ligament may be divided to improve exposure. The mediastinal pleura over the aorta is then opened with long scissors, and a vascular clamp is applied. The dissection of the aorta should be kept to a minimum because of the risk of avulsion of the intercostal arteries. The aortic clamp is removed as soon as the cardiac activity returns and the carotid pulse is palpable.

Air Embolism

In patients with cardiac arrest or severe arrhythmias who have injury to the low-pressure cardiac chambers, the lung, or major veins, air embolism should be suspected. Sometimes, air can be seen in the coronary veins. In these cases, control of the source of the air should be obtained immediately, followed by needle aspiration of the air from the ventricles.

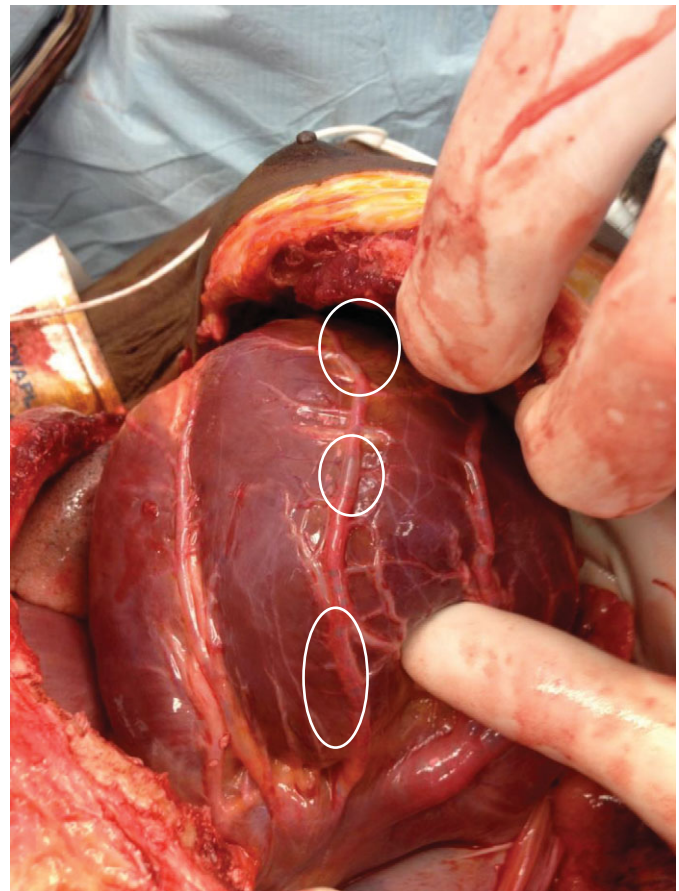


Figure 4.16 Air embolism with air bubbles in the coronary veins. This complication should be suspected in injuries to the low-pressure cardiac chambers, the lung, or major veins.

Hilar Occlusion

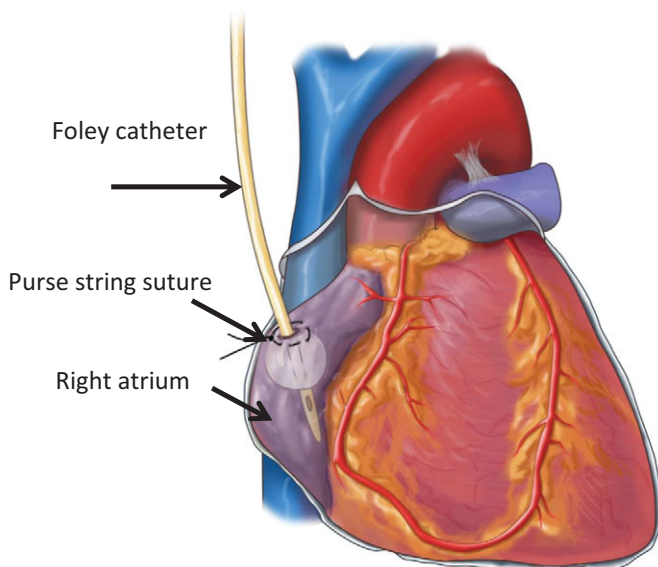
Consider hilar occlusion in cases with lung trauma associated with severe bleeding or air embolism. Digital occlusion of the hilum can be achieved by compression of the hilar structures between the index and the thumb. A vascular clamp can replace the digital compression.

Hilar Twist

This is an alternative approach to the digital or clamp occlusion of the hilum. The inferior pulmonary ligament is divided, taking care to avoid injury to the inferior pulmonary vein. This ligament is a double layer of pleura joining the lower lobe of the lung to the mediastinum and the medial part of the diaphragm. The lower lobe is then rotated anteriorly over the upper lobe to occlude the vasculature, and laparotomy pads are placed to prevent untwisting. Hilar occlusion with a vascular clamp is faster and less traumatic than hilar twist.

Atrial Infusion

Intravenous access may be difficult in patients in extremis. Direct transfusion into the right atrium can be performed. A 2-0 nonabsorbable suture is used to place purse string suture in the right atrium. A Satinski clamp is then applied and the atrium opened with scissors. A foley catheter, or large caliber IV tubing, is then advanced into the atrium and the purse string tightened.



Incision Closure

- The thoracotomy incision should be closed in the operating room, as described in Chapter 3 Thoracostomy Tube Insertion.
- Damage control with temporary closure of the thoracotomy incision should be considered in patients with persistent arrhythmias or who are at high risk for cardiac arrest during the ICU phase of resuscitation. In these cases, immediate access to the heart for cardiac massage may be life-saving. Temporary incision closure is best achieved with the VAC technique.

Tips and Pitfalls

- Common errors with the incision include (a) low incision with an increased risk of injury to the elevated diaphragm and poor exposure of the upper part of the heart, (b) the incision does not follow the curve of the ribs, (c) division of the intercostal muscles with the scalpel with the potential for injury to the underlying inflated lung, (d) injury to the left internal mammary artery if the incision is too close to the sternum, which can be especially problematic if not immediately recognized.
- Common errors during aortic cross-clamping include (a) clamping the esophagus (the aorta is the first structure felt while sliding the fingers along the left posterior wall, just to the left of the spine). A nasogastric tube may help in identifying the esophagus, which is anteromedial to the aorta, (b) injury to the esophagus, (c) avulsion of intercostal arteries, and (d) attempting to clamp a collapsed aorta without any pleural dissection.

Figure 4.17 Rapid fluid transfusion through the right atrium. A Foley catheter or large caliber intravenous tubing is placed through a purse string suture in the right atrium and the suture is tightened.

Intracranial Pressure Monitors

Meghan Lewis and John Peter Gruen

Surgical Anatomy

- Intracranial pressure (ICP) can be measured by a monitor placed into one of the lateral ventricles; in the subarachnoid, subdural, or epidural spaces; or in the brain parenchyma.

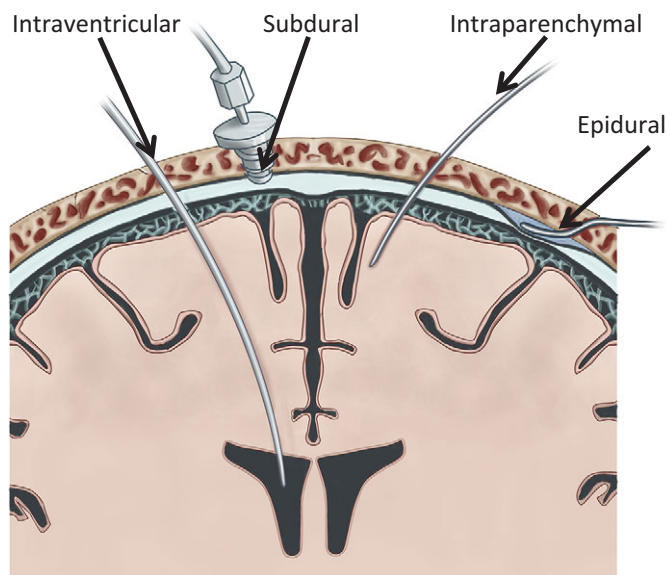


Figure 5.1 The intracranial pressure can be monitored via a catheter placed in one of the lateral ventricles, or with devices placed in the epidural, subdural, or subarachnoid spaces, or in the brain parenchyma.

- ICP monitors should be placed in a patient's nondominant hemisphere (e.g. right hemisphere in a right-handed person).
- Kocher's point is the external skin landmark most commonly used for insertion; at this point, the catheter trajectory to the frontal horn of the lateral ventricle avoids bridging veins, the superior sagittal sinus, and the motor strip. Kocher's point is located 2 cm anterior to the coronal suture at the mid-pupillary line (2–3 cm lateral to midline). The coronal suture is approximately 11–12 cm from the base of the nose.

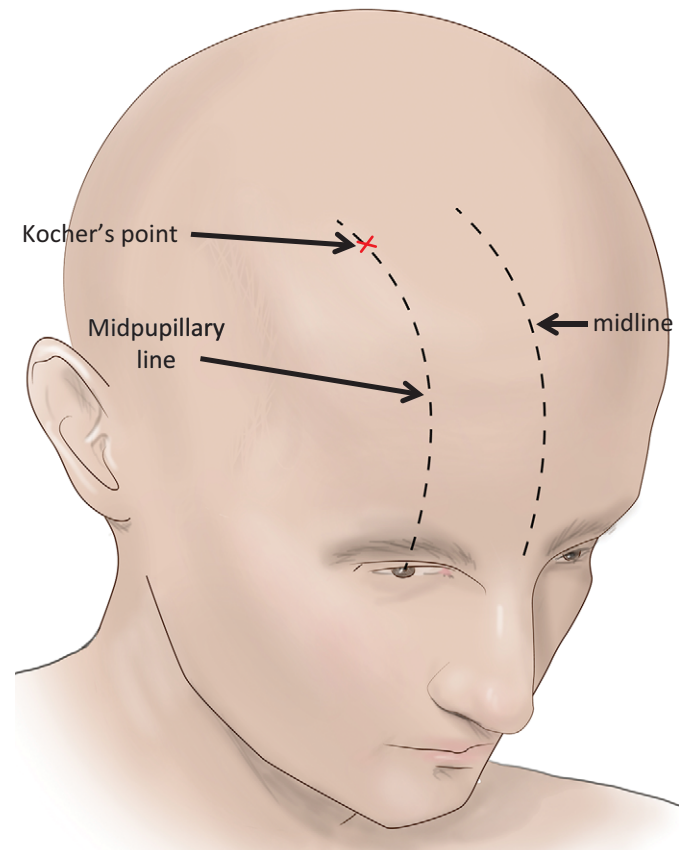


Figure 5.2 Anatomic landmarks for placement of an ICP monitor. Identification of the Kocher's point (red X) for insertion of the ICP monitor: Mid-pupillary line, about 2 cm anterior to the coronal line.

- Alternative sites for placement include Keen's point, which is located 2.5 cm posterior and superior to the top of the ear (posterior-parietal), a Frazier burr hole (occipital-parietal), and Dandy's point (occipital).

General Principles

- The Brain Trauma Foundation recommends management of severe traumatic brain injury (TBI) patients using

information from ICP monitoring to reduce in-hospital and 2-week post-injury mortality.

- Insertion of an ICP monitor may be performed in the emergency room, the operating room, or the intensive care unit.
- Sterile technique should always be utilized for placement.
- Avoid ICP placement if the INR is >1.5
- Complications from ICP monitor placement include hemorrhage, infection, malposition or dislodgement, and cerebrospinal fluid (CSF) leakage.

Types of ICP Monitors

Intraventricular Catheters

- An intraventricular catheter, also called external ventricular drain (EVD), is a flexible catheter inserted into one of the lateral ventricles.
- An EVD can be used both to monitor ICPs and for therapeutic drainage of CSF.
- A fluid coupled EVD is considered the gold standard for ICP monitoring, because it is the most accurate and can be recalibrated in situ. However, alternative methods of pressure transduction are commonly utilized in newer model EVDs.
- Traditional EVDs permitted measurement of ICP only when the drain was closed; however, newer models allow simultaneous ICP monitoring and CSF drainage.

Microtransducers

- Microtransducers utilize fiber optic, strain gauge, or pneumatic sensors to continuously monitor ICPs. These are often placed into the desired space through a hollow screw, also called a “bolt.”
- Microtransducers have a lower infection risk than EVDs; however, they do not allow for drainage of CSF.
- Microtransducers are generally easier to place than EVDs, and can be positioned in several locations:
 - Intraparenchymal
 - Subarachnoid
 - Subdural
 - Epidural
 - Intraventricular

Special Surgical Instruments

- Commercialized drill kits are available containing the instruments necessary for placement of an ICP monitor. These kits generally contain:
 - A scalpel
 - A self-retaining retractor
 - A twist drill with narrow and wide bits

- An irrigating syringe
- Sterile saline
- A spinal needle
- A catheter with trocar and/or a hollow screw (“bolt”)
- A tunneler
- A connector
- Additional equipment that may be required includes:
 - A marking pen
 - A measuring tape
 - Local anesthetic
 - Additional syringe
 - Needles



Figure 5.3 Contents of a typical drill kit for placement of an ICP monitor.

Patient Positioning

- The patient should be positioned in reverse Trendelenburg with the head of bed elevated 30°.
- The head should be immobilized in a neutral position.

Procedure

- Adequate analgesia and sedation should be administered.
- The hair should be clipped around the intended site. Hair should not be shaved due to increased risk for infection.
- The site should be prepped with antiseptic solution and draped in standard sterile fashion. Appropriate sterile gown and gloves, surgical mask, eye protection, and hair covering should be used.
- The important anatomic landmarks are first marked, including the midline, the mid-pupillary line, the coronal suture, and Kocher's point.

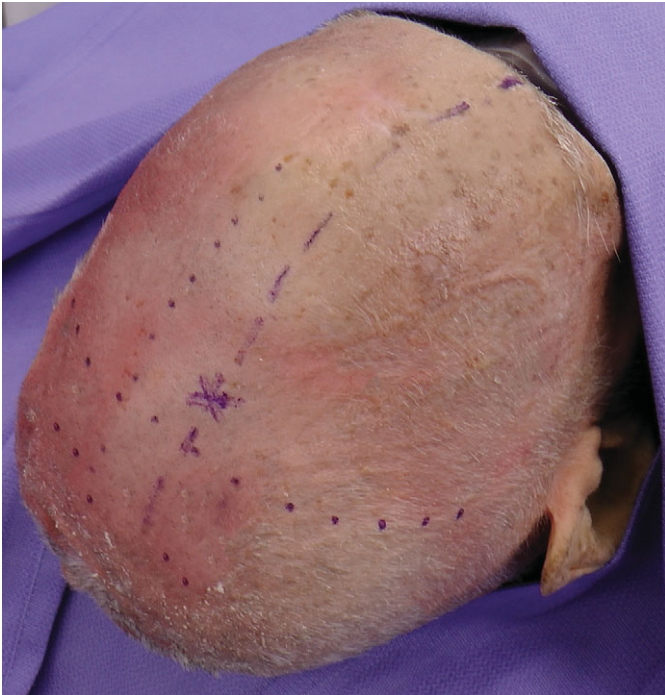


Figure 5.4 Important landmarks are identified, including the midline, mid-pupillary line, coronal suture, and Kocher's point.

- Local anesthetic should be injected in the skin and subcutaneous tissue at Kocher's point.
- A 1–2 cm incision should be made to the bone at Kocher's point, and the skull cleared of periosteum.



Figure 5.5 An incision is made at Kocher's point.

- A self-retaining retractor can be used in the skin, if desired.
- Using a twist drill positioned perpendicular to the skull, a burr hole is created, penetrating both the outer and inner

tables of the skull. The narrow bit should be used for placement of an intraventricular catheter, and the wider bit is used for placement of a bolt. A decrease in resistance indicates penetration of each table. A stop guard can also be used to prevent accidental entry into the brain parenchyma when the inner table of the skull is breached.

- As a result of drilling, bone fragments and dust accumulate at the site of the burr hole. These should be completely irrigated away using sterile saline.



Figure 5.6 The drill is positioned perpendicular to the skull, and a burr hole is created.

- A spinal needle should be used to confirm penetration through all of the skull.



Figure 5.7 A spinal needle is used to confirm penetration of both tables of the skull.

- An 11-blade scalpel is then used to create a small cruciate incision in the dura.



Figure 5.8 A cruciate incision is made in the dura.

- If a bolt is being placed, it is screwed in at this time, so that it abuts the subdural space. A pressure transducer is then inserted, and the procedure is completed.

(a)



(b)



Figure 5.9 (a) A bolt is screwed into the incision site until it abuts the dura. (b) A microtransducer is inserted through the bolt.

- If an intraventricular catheter is being placed, it should be inserted on its trocar through the burr hole, perpendicular to the brain, aiming toward the medial canthus of the ipsilateral eye. Intraventricular catheters generally require advancement 5–7 cm before a decrease in resistance is encountered, and upon removal of the trocar, cerebrospinal fluid is expressed. These two findings confirm entry into the lateral ventricle. If CSF is not encountered, up to two additional attempts may be made, with the catheter directed slightly more medially each time.



Figure 5.10 An intraventricular catheter is inserted on its trocar, aiming for the ipsilateral medial canthus.

- The tunneler is then inserted under the skin at the insertion site, tunneled through the subcutaneous tissue, and pierced out the skin about 5 cm away.



Figure 5.11 A tunneler is inserted through the incision and tunneled under the skin for 5 cm.

- The catheter should then be attached to the posterior aspect of the tunneler, so that the tunneler can be pulled completely through the skin, and the catheter will follow. Tunneling the catheter reduces the risk for infection.
- The insertion site is also sutured closed, and a sterile gauze dressing should be placed.
- The monitor should be zeroed at the level of the external auditory meatus.

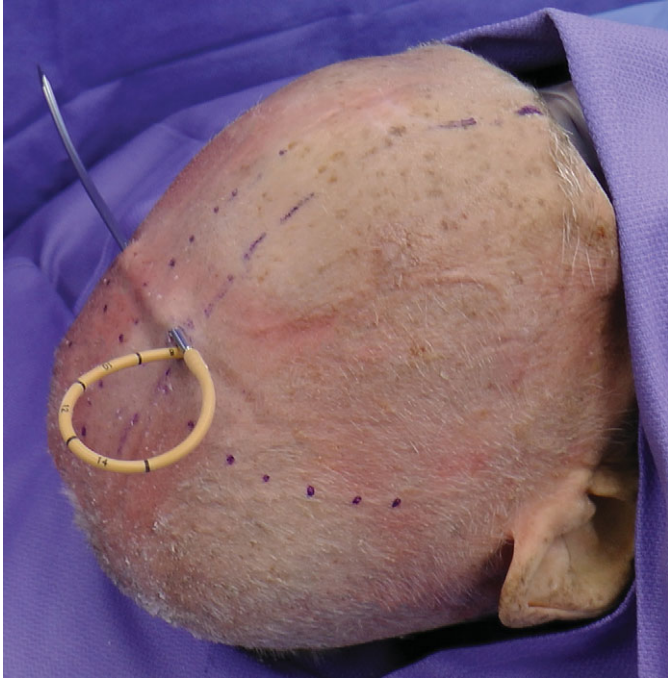


Figure 5.12 After the tunneler has pierced the skin 5 cm from Kocher's point, the catheter is attached to the posterior aspect of the tunneler.

- The catheter is then sutured to the skin with nylon suture, and capped with a connector.

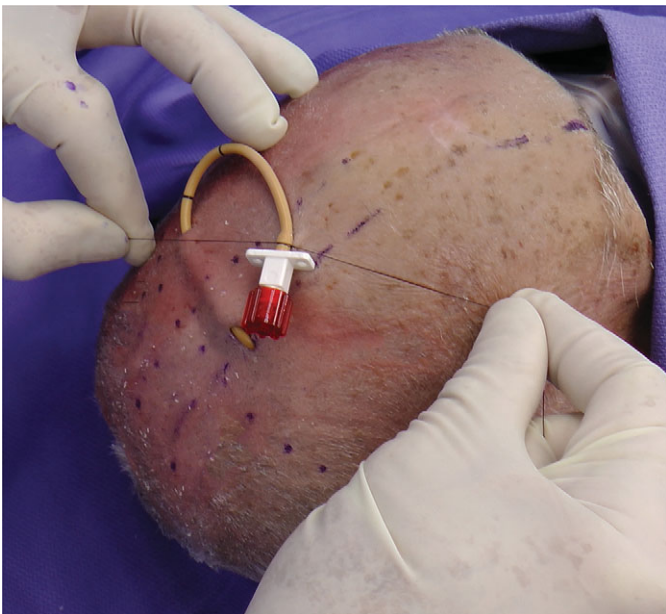


Figure 5.13 The catheter is capped with connector and sutured to the skin.

Tips and Pitfalls

- Scalp infection is a relative contraindication to placement of an ICP monitor.
- Intraventricular hemorrhage is a contraindication to ipsilateral EVD placement.
- Thrombocytopenia ($<100,000$) and INR >1.5 should be corrected to reduce hemorrhage from placement.
- No more than three attempts should be made at placement of an EVD, because complications increase significantly with greater than three attempts.
- An EVD may be difficult to place if the ventricles are compressed or displaced due to significant mass effect. An alternative type of monitor can be utilized in this situation.
- Excessive loss or drainage of CSF should be avoided, as the brain may not tolerate sudden decompression of the ventricles.

Evacuation of Acute Epidural and Subdural Hematomas

Gabriel Zada and Kazuhide Matsushima

Surgical Anatomy

- There are three meninges covering the brain: the dura mater, the arachnoid mater, and the pia mater.
 - The dura mater is the thickest and strongest membrane, and is firmly attached to the inner surface of the cranial bone, especially along the sutures. It *contains the meningeal arteries*.
 - The arachnoid mater is a thin membrane under the dura mater. Its inner surface has numerous thin trabeculae extending downward, into the subarachnoid space.
 - The pia mater is a thin membrane that covers the surface of the brain, entering the grooves and fissures.
- Due to the tight adhesion of the dura mater to the inner skull, significant force is required to separate them. In contrast, separation of the dura from the subarachnoid mater can occur with relatively little force.
- The middle meningeal artery arises from the external carotid artery. It enters the foramen spinosum and branches into the anterior, middle, and posterior branches with various patterns. It is a common source of bleeding in acute epidural hematomas (EDHs).
- The bridging veins connect the cortical superficial veins to the sagittal sinus in the dura. They are a common source of bleeding in acute subdural hematomas (SDHs).

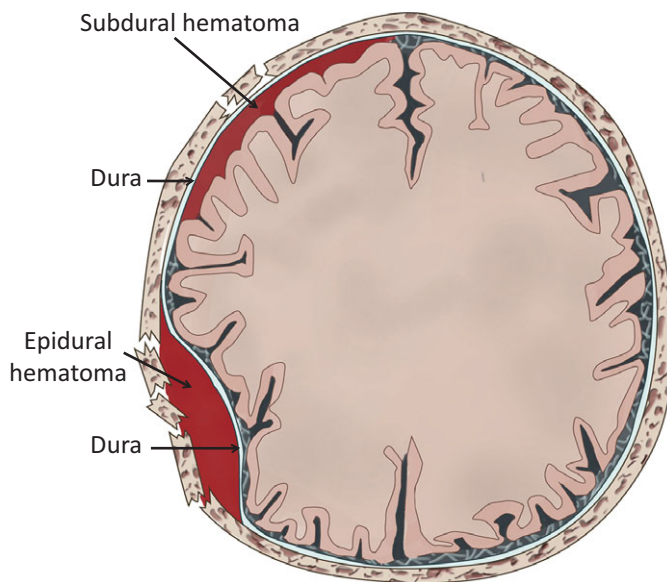


Figure 6.1 Epidural hematomas develop in the space between the inner table of the skull and the dura. Subdural hematomas develop in the space between the dura and arachnoid.

General Principles

- Acute EDH and SDH are commonly caused by blunt mechanisms (e.g. motor vehicle accident, fall, assault).
- EDH develop when blood collects in the space between the inner table of the skull and the dura; SDH occur when blood collects between the dura and arachnoid.
- EDHs are often due to injury to the meningeal arteries, usually the middle meningeal artery, associated

with skull fractures in the temporal region. A torn dura venous sinus or bleeding from a skull fracture may also result in EDH. The hematoma is located between the inner plate of the skull and the dura mater.

- Although the temporal region is the most common site for EDH, they may occur almost anywhere in the cranial cavity.

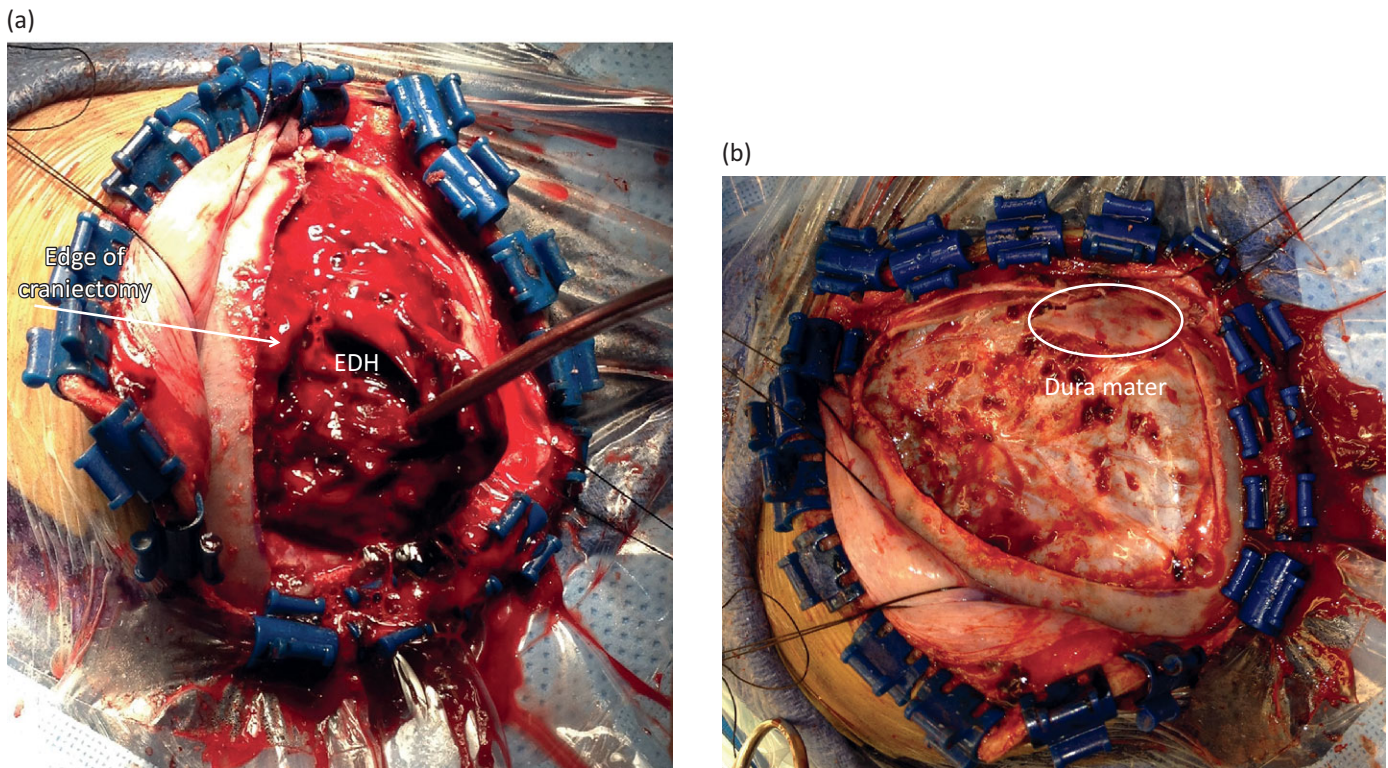
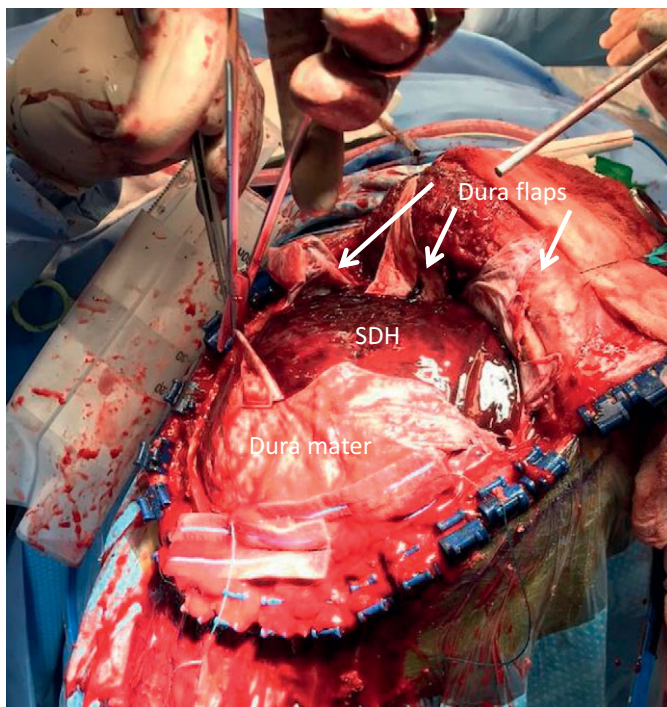


Figure 6.2 (a) Appearance of a large epidural hematoma after craniotomy. The hematoma is located between the inner plate of the skull and the dura mater. (b) Appearance of the intact dura mater after evacuation of the epidural hematoma. Note the fracture of the skull (circle), which was the primary cause of the bleeding.

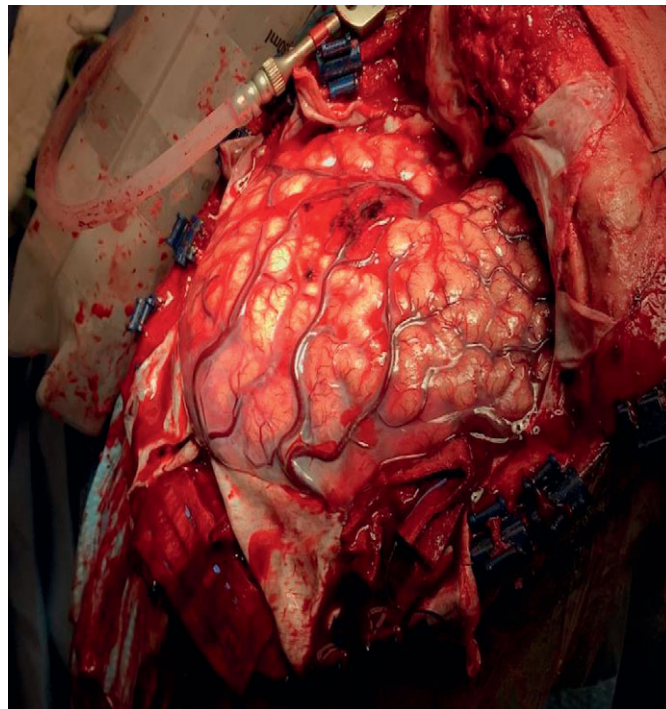
- Acute SDHs is commonly caused by bleeding from brain parenchymal injury or from torn bridging veins, which connect the cortical superficial veins to the sagittal sinus in the dura. The hematoma is located between the dura mater and the arachnoid mater.

Figure 6.3 (a) Intraoperative appearance of a large subdural hematoma under the dura mater, after craniotomy and opening of the dural mater. (b) Intraoperative appearance after evacuation of the subdural hematoma. Note the brain is exposed and edematous.

(a)



(b)



- The acute EDH appears as a high-density lenticular (biconvex)-shaped lesion, often associated with an overlying skull fracture. It usually does not cross suture

lines. The acute SDH appears as a crescent-shaped lesion that may cross suture lines.

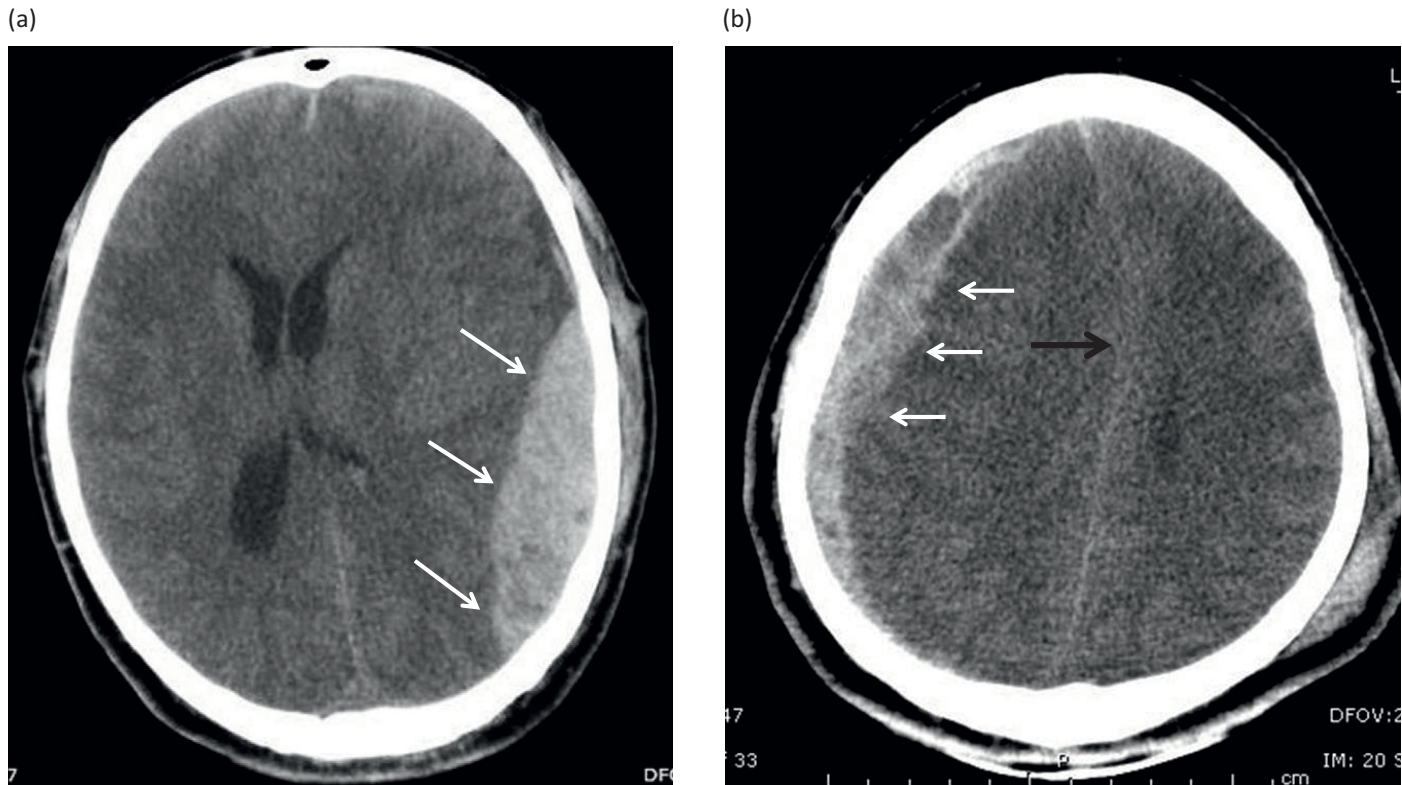


Figure 6.4 (a) CT scan appearance of an acute epidural hematoma. Note the lenticular (biconvex) shape of the hematoma (arrows). (b) CT scan appearance of an acute subdural hematoma. Note the crescent shape of the hematoma (white arrows). There is a significant midline shift (black arrow).

- Patients with EDH/SDH may present with a wide array of clinical manifestations, from mild headache to coma. A classic “lucid interval” (brief loss of consciousness with recovery followed by neurological deterioration) is seen in only half of patients with acute EDH.
- EDHs are typically caused by arterial sources of bleeding, and, therefore, often have a more rapid time course to neurological deterioration. Many SDHs, on the other hand, are caused by venous sources, and may accumulate and exert neurological effects via a slower progression pattern.
- Emergency surgical evacuation of EDH or SDH by craniotomy is often required to prevent death and long-term functional disability.
- Acute SDHs are commonly caused by bleeding from brain parenchyma trauma or the bridging veins which cross the subdural space. The bridging veins connect the cortical superficial veins to the sagittal sinus in the dura.
- Elderly people are more likely to develop SDH due to cerebral atrophy associated with increased fragility and tension of the bridging veins. On the other hand, elderly people are less likely to develop EDH because of the fibrosis and firmer attachment of the dura mater to the skull.

Indications for Surgical Intervention

- The decision for surgical evacuation of EDH or SDH is typically based on an assessment of a variety of clinical,

systemic, and imaging findings. The neurological examination, including the Glasgow Coma Scale (GCS), pupillary findings, and motor function, is a major consideration. Systemic considerations include associated injuries, hemodynamic instability, coagulopathy, and comorbidities. Other objective information that weighs on this decision-making process includes CT findings (e.g. large EDH in a patient with only headache) and high intracranial pressure (ICP) in patients with ICP monitor.

- Medical management in patients with EDH or SDH, and a concern for elevated ICP includes elevating the head of the bed, sedation/intubation as needed, mild hyperventilation, hyperosmolar therapy, reversal of coagulopathy, seizure control, and potentially barbiturate-induced coma.
- Surgical evacuation is generally recommended for adult patients with EDH volume $>30 \text{ cm}^3$ on CT scan regardless of GCS. In many patients with GCS <9 , anisocoria on pupillary exam, thickness of hematoma $>15 \text{ mm}$ or midline shift $>5 \text{ mm}$ on CT scan, surgical evacuation may also be warranted. In pediatric patients with acute EDH, the threshold for surgery is often lower than in adult patients. Location of the EDH also plays an important role, with temporal and posterior fossa EDHs often warranting a lower threshold for evacuation because of their propensity to cause uncal herniation and hydrocephalus or brainstem compression, respectively.

(a)



(b)

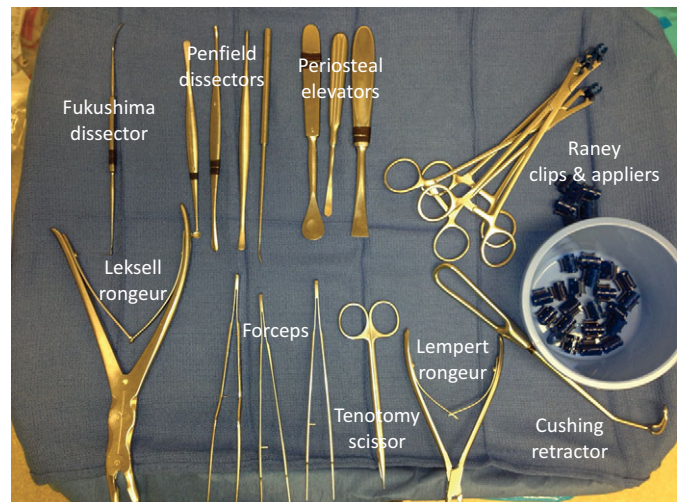


Figure 6.5 (a, b) Basic instruments for craniotomy.

- The indications for surgical evacuation of acute SDH often include hematoma thickness >10 mm or midline shift >5 mm on CT scan (regardless of GCS), anisocoria, sustained ICP >20 mmHg or decreased GCS by ≥ 2 points from injury to admission.

Special Surgical Instruments

- A setup for emergency craniotomy should include: Raney scalp clips, Hudson brace hand-drill or air-powered (pneumatic) drill, burrs, and Gigli wire saw or electric bone saw (craniotomy).
- Headlights and surgical loupes are recommended.
- Hemostatic products (e.g. oxidized cellulose, gelatin sponge, etc.).

Patient Positioning

- The patient is placed in the supine position under general anesthesia with both arms tucked. The head is usually elevated above the level of the heart (typically with reverse

Trendelenburg position) to promote venous outflow and reduce ICP. For a posterior fossa or occipital hematoma, prone position may be required.

- The patient's head is rotated to the contralateral side of craniotomy, 0° – 15° from the horizontal plane. A shoulder roll is placed to facilitate head turning. This is especially required for patients with potential cervical spine injury who must remain in rigid collar fixation.
- The patient's head is supported with a donut pillow or horseshoe head holder. Mayfield pin fixation systems are not required for most cases in supine position.

Incision for Craniotomy

- The entire scalp or the ipsilateral region of interest is shaved, prepped, and draped. A dose of antibiotics should be administered prior to skin incision.
- The exact position of the incision varies and depends on the location of the hematoma, but it should never reach the midline, at the top of the skull.

- The usual incision starts at the zygomatic arch, anterior to the tragus. This is extended to (1) the summit, (2) the external occipital protuberance, and (3) the vertex ending at the hairline. Careful consideration (and avoidance) of midline structures must be maintained at all times.

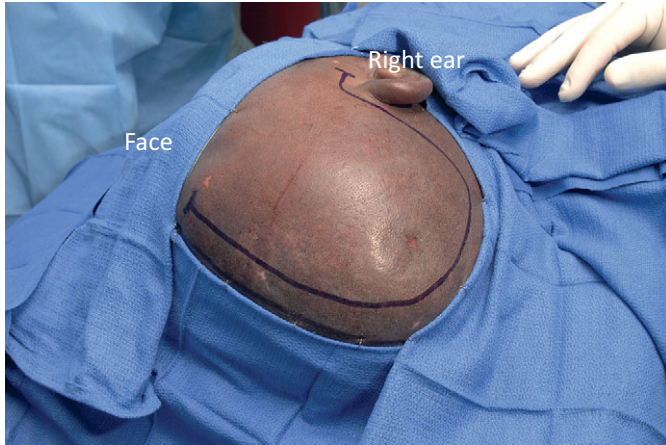


Figure 6.6 Right craniectomy. Skin incision is made starting at the zygomatic arch anterior to the tragus to the vertex, ending at the hairline (question mark incision). The incision should avoid the midline, at the top of the skull in order to prevent injury to the sagittal sinus.

- Scalp bleeding is controlled with the electrocautery, and Raney clips are applied to achieve hemostasis along the edge of the scalp incision. The temporalis fascia and muscle are split, and the scalp/temporalis musculocutaneous flap are elevated together to avoid injury to the frontalis branch of the facial nerve.

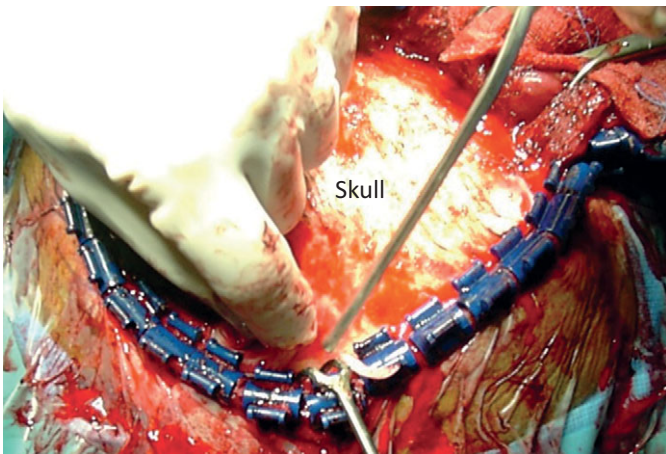


Figure 6.7 Application of Raney clips on the edges of the incised scalp achieves hemostasis.

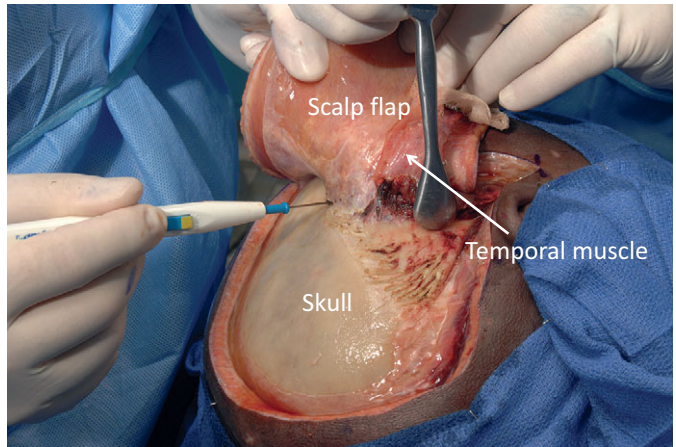


Figure 6.8 A musculocutaneous flap is made to expose the skull for craniotomy. The scalp/temporalis musculocutaneous flap are opened together to avoid injury to the frontalis branch of the facial nerve.

Technical Pitfalls

- Maintain awareness of the location of the midline at all times. Avoid midline at the top of the skull to prevent injury to the sagittal sinus
- Be careful to avoid injury to the frontal branch of the facial nerve, located 1 cm anterior to the tragus.

Burr Holes and Bone Flap Removal

- For patients with large, hemispheric lesions (usually SDH), four burr holes are created using either a hand drill or a pneumatic/electric drill. Burr holes are placed in the: (1) temporal squama (thin part of the temporal bone above the root of zygoma), (2) parietal area, (3) frontal area, and (4) pterion (area behind the zygomatic arch of the frontal bone).

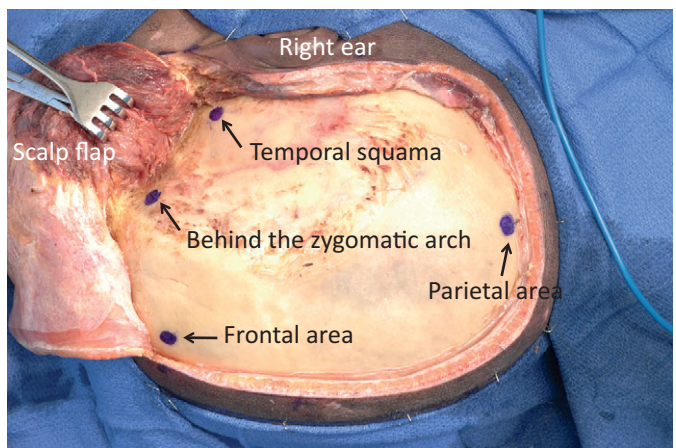


Figure 6.9 Sites of the burr holes for large, hemispheric lesions.

- In patients with localized/confined EDH (e.g. temporal EDH), three burr holes can be placed surrounding the confines of the hematoma. (In cases with EDH, the hematoma is often encountered immediately following placement of the burr hole).
- The Burr holes can be created using a hand-held or a pneumatic drill. The drill is always placed perpendicular to the skull.
 - The hand-held drill should be advanced carefully with a pointed bit (first bit) until the inner table is penetrated and the dura is barely exposed. Then, the drill bit with more of a curvature (second/third bit) is used to widen the hole.
 - The pneumatic drill pit stops spinning on penetrating the inner table of the skull. A curette or rongeur is used to remove the remaining bone fragments.
- The dura is dissected off the inner table of the skull using a Penfield dissector or angled Fukushima instrument to prevent the violation of the dura and brain tissue underneath. Bleeding from the bone edge is controlled with bone wax.

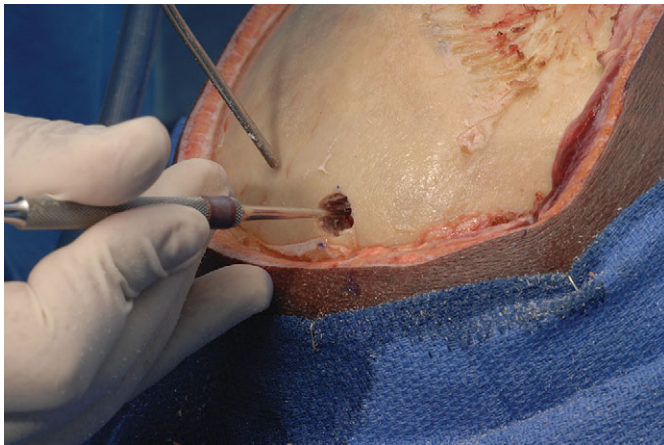


Figure 6.10 The dura is dissected off the inner skull using a dissector.

- The burr holes are then connected using an air-powered bone saw (craniotome). A thin metal strip can be placed between the skull and the dura. The craniotome also has a protective footplate. The bone flap is subsequently removed carefully from the underlying dura. Again, great care should be taken to avoid midline structures (sagittal sinus) in this step. The bone flap is preserved in a sterile location.

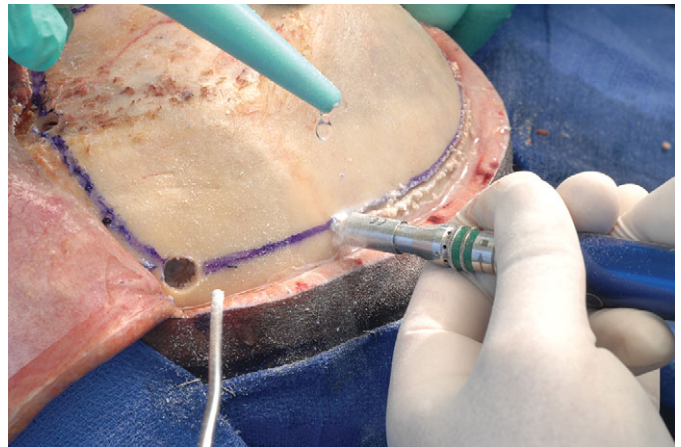
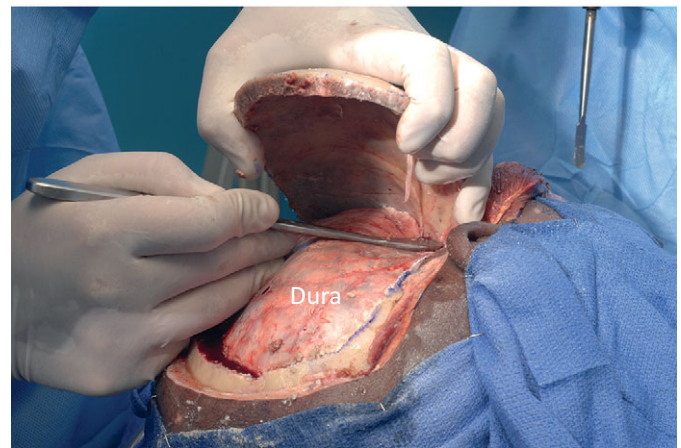


Figure 6.11 Burr holes are connected with a bone saw to create a bone flap.

(a)



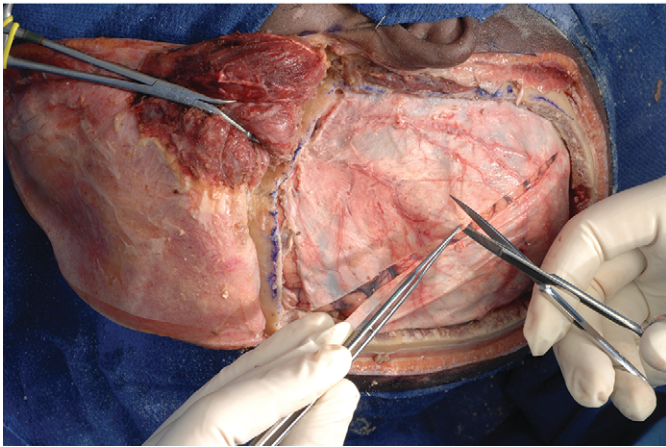
(b)



Figure 6.12 (a, b) A bone flap is removed with attention to avoid injury to the sagittal midline.

- In patients with EDH, the hematoma can be evacuated at this time. The offending (bleeding) vessel can be identified and coagulated at this time. The dura is tacked up to the surrounding bone to prevent reaccumulation of hematoma.
- In cases of SDH, the durotomy is created in a cruciate, stellate, or semicircular fashion. The dura is tacked up, and the hematoma is evacuated using gentle suction and irrigation.

(a)



(b)

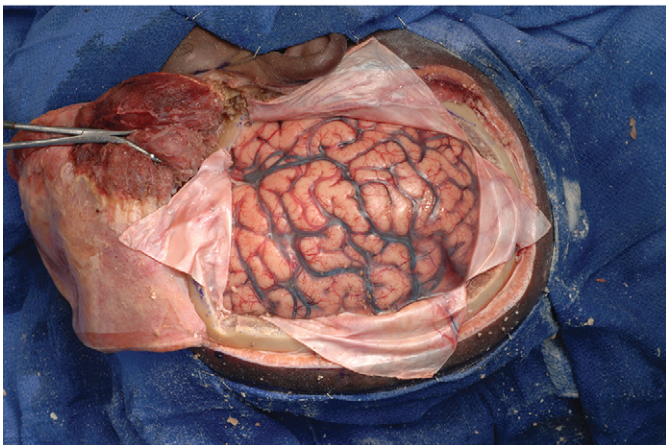


Figure 6.13 (a, b) For evacuation of a subdural hematoma, the dura is opened in a cruciate, stellate, or semi-circular fashion.

Technical Pitfalls

- To avoid injury of the superior sagittal sinus or arachnoid granulation by making the burr holes in the frontal and parietal area, these holes should be created at least 1–2 cm off the midline.
- Additional bone removal at the temporal base may be performed using a single-action or double-action rongeur to achieve complete decompression of the medial temporal structures (uncus), ambient cisterns, and brainstem.

Evacuation of Hematoma and Bleeding Control

- The main purposes of surgery for this particular indication are evacuation of hematoma, establishment of hemostasis, and preventing reaccumulation of hematoma.
- Aggressive reversal of coagulopathy, using blood products (e.g. fresh frozen plasma, prothrombin complex concentrate, platelets) should be considered.
- Once the hematoma is encountered, clot is removed with forceps, irrigation, and/or suction. The source of bleeding can be from (1) arterial injury, (2) venous injury, (3) brain parenchymal injury, (4) fractured bone fragments, and (5) venous sinus bleeding. The bleeding site may not always be identified at the time of surgery (particularly venous bleeding that has thrombosed/clotted by the time of surgery).
- Arterial bleeding can be cauterized using a bipolar coagulator. Avoid cauterizing intact veins as extensive venous infarction may occur. Several types of topical hemostatic agents (e.g. oxidized cellulose, gelatin sponge) can be used to achieve hemostasis.

Technical Pitfalls

- Great care must be taken to avoid the iatrogenic injury to the brain parenchyma when hematoma is evacuated using a suction tip or any other instruments. A variety of cottonoids can be used to protect the brain.
- To control bleeding outside the area of exposure, additional removal of bone may be required. Attempting to achieve hemostasis without direct observation (e.g. under surrounding skull), which may cause further injury to vessels or brain parenchyma, should be avoided.

Closure

- Once the hematoma is evacuated and bleeding is controlled, a Valsalva maneuver can be performed to verify that hemostasis has been achieved.
- In EDH cases, a small durotomy may be made to rule out the presence of associated SDH.
- When possible, the dura is closed in a watertight manner. In cases with significant brain edema, the bone flap is not replaced (craniectomy), and a dural substitute overlay is often used to protect the brain prior to scalp closure.

- A decision should be made whether to replace the bone flap, and whether any epidural drains would benefit the patient. Our preference is to use round drains (Blake or round Jackson-Pratt drains) when necessary, which are more easily removed at the bedside. Drains can be tunneled out of a burr hole and through the scalp, lateral to the incision.
- To prevent the development or recurrence of EDH postoperatively, the dura can be tacked up to the surrounding bone in a circumferential manner by drilling small holes in the surrounding bony edges, and suturing the dura to these holes using 4-0 Neurilon sutures.
- ICP monitoring may be useful for postoperative management, and a monitor can be placed (often contralaterally to the operative site) prior to, during, or following the operation.
- When indicated, the bone flap is replaced and secured using standard bone fixation plates. This is not possible in the presence of severe brain swelling.
- If there is no brain swelling, the bone flap is replaced and secured back on the skull defect, using standard bone fixation plates. However, this is not possible in the presence of severe brain swelling. Cranioplasty is performed later on with either sterile autologous skull flap (subcutaneous layer placing or cryopreservation) or bone substitutes (e.g. titanium, calcium phosphate).

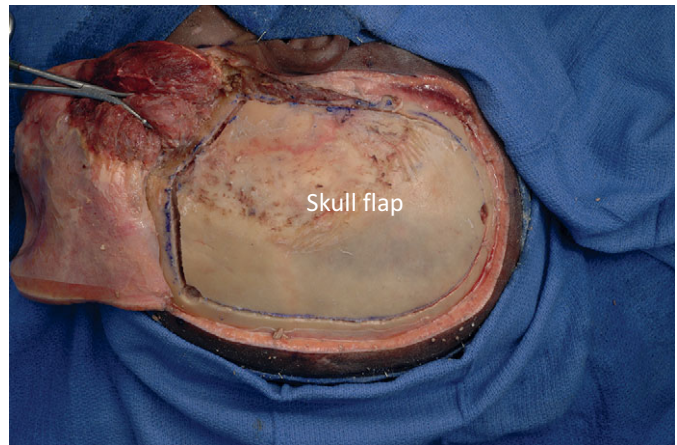


Figure 6.14 The bone flap is placed after hematoma evacuation. For severe brain swelling, the bone flap is left out.

- A separate drain can be placed underneath the galea as needed. The temporalis fascia is reapproximated. Following irrigation, closure of scalp proceeds in two layers (galea aponeurotica, skin).

Technical Pitfalls

- In cases of significant brain edema, the bone flap should not be replaced (decompressive craniectomy).

Neck Operations for Trauma

General Principles

James Bardes, Emilie Joos, and Kenji Inaba

Surface Anatomy

- For trauma purposes the neck is divided into three distinct anatomical zones.
 - Zone 1: from the sternal notch to the cricoid cartilage.
 - Zone 2: from the cricoid cartilage to the angle of the mandible.
 - Zone 3: from the angle of the mandible to the base of the skull.
- Knowing the contents of each zone is important when considering possible injuries.
 - Zone 1: the major vessels of the upper mediastinum, the lung apices, esophagus, trachea, thoracic duct, and thyroid gland.
 - Zone 2: the carotid sheath and contents, vertebral arteries, esophagus, trachea, pharynx, and the recurrent laryngeal nerve.
 - Zone 3: distal carotid and vertebral arteries, distal jugular veins.

- At the level of the superior border of the thyroid cartilage the common carotid artery bifurcates into the internal and external carotid arteries.
- At the level of the angle of the mandible, the internal and external carotid arteries are crossed superficially by the hypoglossal nerve and the posterior belly of the digastric muscle.
- The external landmark of the pharyngoesophageal and laryngotracheal junctions is the cricoid cartilage. On esophagoscopy, this is located 15 cm from the upper incisor teeth.
- The cricothyroid membrane is four fingerbreadths above the sternal notch.

General Principles

- Overall, approximately 1/3 of all gunshot wounds and 1/5 of stab wounds to the neck result in significant injuries to vital structures. Transcervical gunshot wounds are associated with the highest incidence of significant injuries.

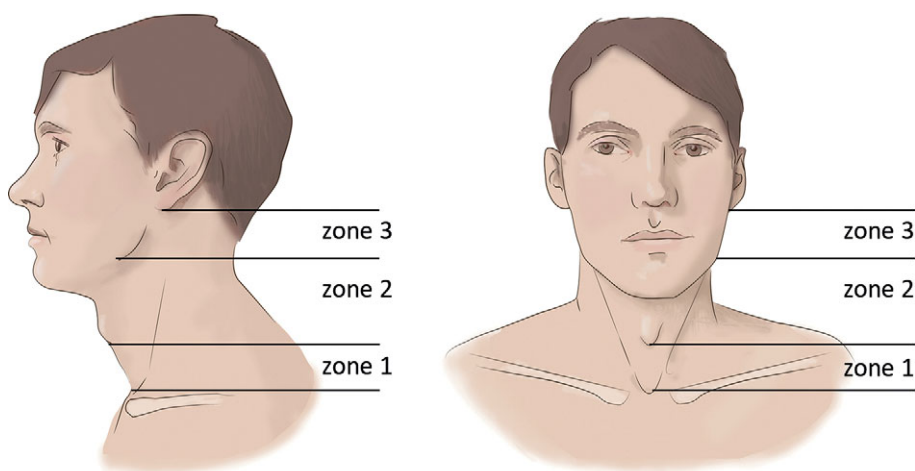


Figure 7.1 For trauma purposes, the neck is divided into three distinct anatomical zones. Zone 1, from the sternal notch to the cricoid cartilage. Zone 2, from the cricoid to the angle of the mandible. Zone 3, from the angle of the mandible to the base of the skull.

- The incidence of tracheal or esophageal injury is approximately 10% for gunshot wounds and 5% for stab wounds.
- Cervical spine injuries after penetrating trauma are extremely rare.
- Patients with hard signs of vascular injury (pulsatile bleeding, large or expanding hematoma, bruit or thrill, and shock) or aerodigestive tract injury (massive hemoptysis or hematemesis, air bubbling from a wound) should proceed directly to the OR.
- All remaining patients with soft signs of vascular injury (small and nonexpanding hematoma or minor bleeding) or aerodigestive tract injury (hoarseness, minor hemoptysis, or hematemesis) should undergo CT Angiography. Treatment is then based on the CT results and trajectory. In the case of equivocal CT results, the selective use of catheter-based angiography, endoscopy, and bronchoscopy can be utilized to rule out an injury. CT Angiography is the optimal screening imaging modality; it will decrease the number of negative neck explorations and allow targeted treatment of injuries.
- Asymptomatic patients can have their wounds closed and be observed.
- About 10% of patients with penetrating neck trauma present with airway compromise due to direct trauma to the larynx or trachea, or due to external compression by a large hematoma.
- Establishing an airway is a critical first step. This can be a difficult and potentially dangerous procedure. Fiberoptic intubation may increase success rates, and decrease the chance of worsening a partial injury. If possible, these patients should be taken to the operating room for airway management. Equipment for a cricothyroidotomy should be available, and the surgeon ready to perform a surgical airway.
- Bleeding from a deep penetrating injury to the neck may be controlled by direct digital pressure in the wound, or placement of a Foley catheter into the wound and inflation of the balloon with sterile water. For some injuries, multiple Foley catheters may be needed to obtain hemostasis.

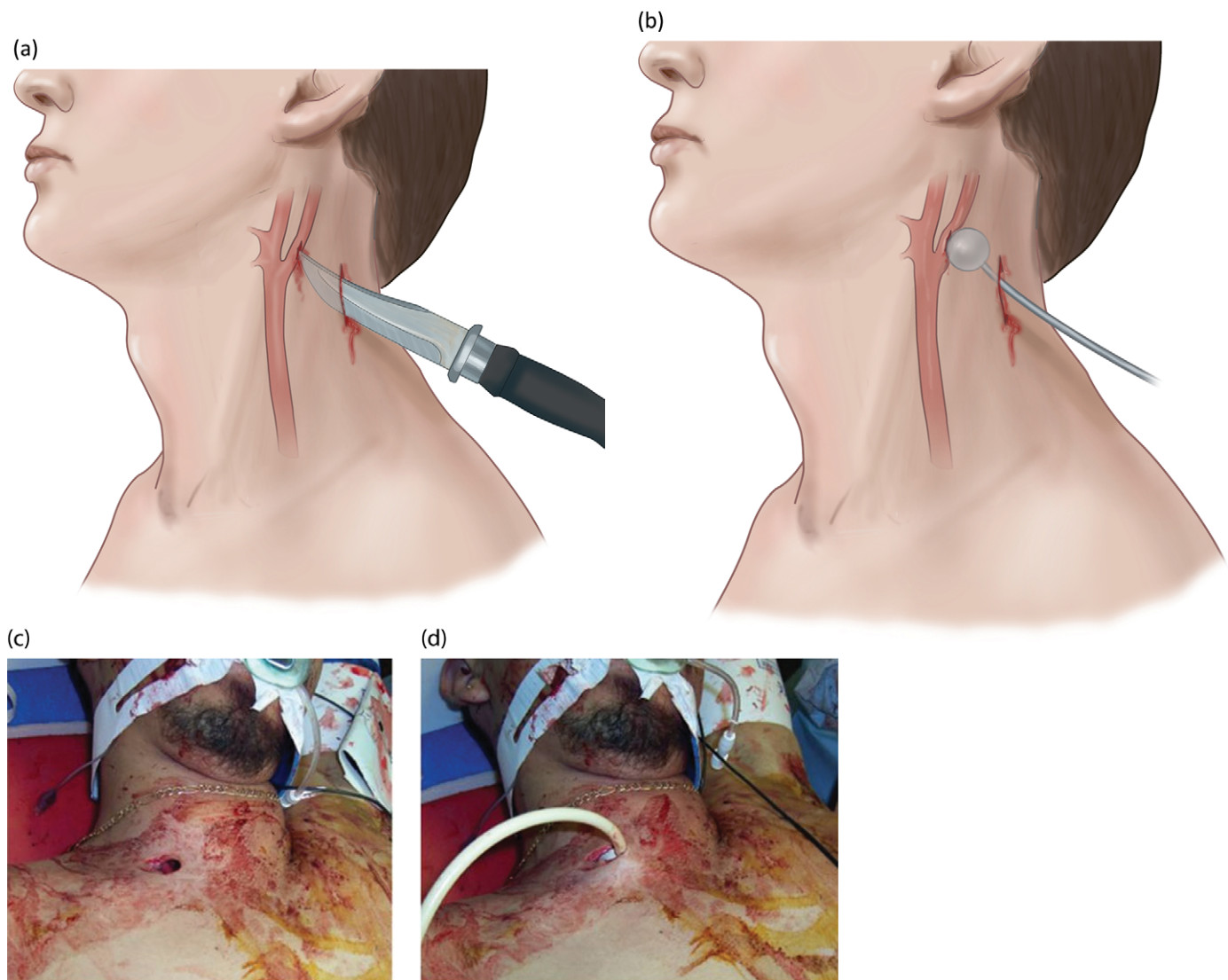


Figure 7.2 Bleeding from a deep penetrating injury to the neck may be controlled by the placement of a Foley catheter into the wound and then inflating the balloon with sterile water.

- Always place intravenous lines in the arm opposite the injury, especially in supraclavicular injuries with suspected subclavian vessel injury.
- In suspected major venous injury, air embolism must be a primary concern. Place the patient in the Trendelenburg position, and occlude the wound in order to reduce the risk of this serious complication.

Positioning

- The patient should be in the supine position with arms abducted.
- If there is no clinical concern for cervical spine injury, a roll should be placed under the shoulders to provide extension of the neck.
- If a sternocleidomastoid incision is planned, the head is turned to the opposite side of the injury. For a collar incision, the head is kept in the midline position.

Special Instruments

- Vascular instruments and sternotomy equipment should be available.
- A rigid or flexible endoscope and bronchoscope should be available to allow examination of the entire airway and upper digestive tract.

Skin Preparation

- Prep the patient's neck widely, from ear to ear, chin to abdomen, and to the axilla bilaterally. This allows for extension of the incision onto either side of the neck, as well as exploration of the chest for proximal injuries.
- Prepare both groins for possible vein harvesting.
- Perioperative antibiotics should be given.
- Towels should be placed in the recesses above the shoulders.
- A clear drape should be placed from the chin upwards, so that the airway is visible and accessible to the surgeon, and to facilitate joint airway manipulation with anesthesia.

Incisions

Three major incisions allow access to the neck. The anterior sternocleidomastoid, the clavicular, and the collar incision. The sternocleidomastoid is versatile, familiar to most surgeons, and used in most cases. The collar incision is used in limited circumstances for central airway injuries. The collar incision can be combined with a unilateral or bilateral sternocleidomastoid incision if additional exposure is necessary. The clavicular incision is used for exposure of the subclavian vessels. A median sternotomy may be added to the sternocleidomastoid or the clavicular incisions for more proximal exposure.

1. Anterior sternocleidomastoid incision

- This incision is made over the anterior border of the sternocleidomastoid muscle and extends from just below the mastoid to the sternal notch.
- The incision can be extended down to the sternum for access to the thoracic inlet, and up to the mastoid process to expose the vertebral artery and the distal internal carotid artery.

- This incision is the most versatile. It provides excellent exposure to the carotid arteries, the jugular vein, the vertebral artery, and the cervical aerodigestive tract.

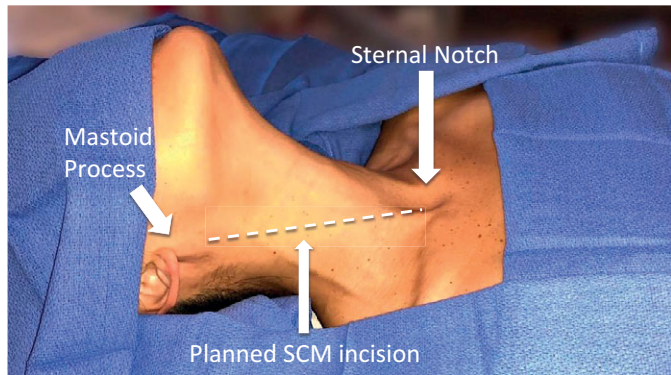


Figure 7.3 The patient is positioned for a sternocleidomastoid incision. The head is slightly extended and rotated away from the side of incision. The incision is then made from the mastoid process to the sternal notch, along the anterior border of the SCM.

2. Collar incision

- The collar incision is made approximately two fingerbreadths above the sternal notch, extending to the medial borders of the sternocleidomastoid muscles bilaterally.
- It is commonly used for repair of a central airway injury. This incision is severely limiting for esophageal exposure, and should be avoided if an esophageal injury is suspected.
- If additional exposure is needed, a sternocleidomastoid incision can be added to either side, or performed bilaterally.

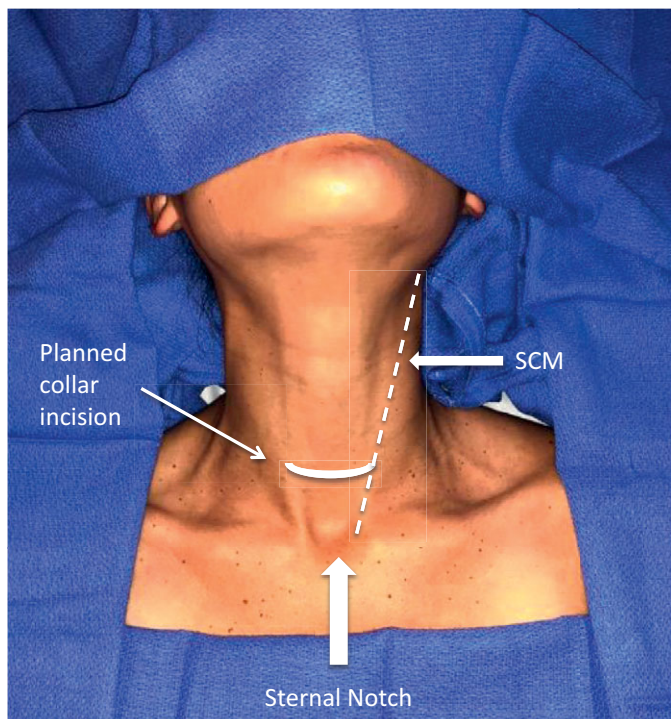


Figure 7.4 The patient is positioned for a collar incision. The head is extended slightly to facilitate dissection. The incision is placed two fingerbreadths above the sternal notch and extends to the SCM bilaterally.

3. Clavicular incision

- This is the standard incision for the exposure of the subclavian vessels. It may be combined with a median sternotomy, for exposure of the proximal subclavian vessels or upper mediastinal vascular structures.
- It begins at the sternoclavicular junction, extends over the medial half of the clavicle, and, at the middle portion of the clavicle, it curves downwards into the deltopectoral groove.
- The clavicle may be divided near the sternum and retracted to expose the proximal subclavian artery.

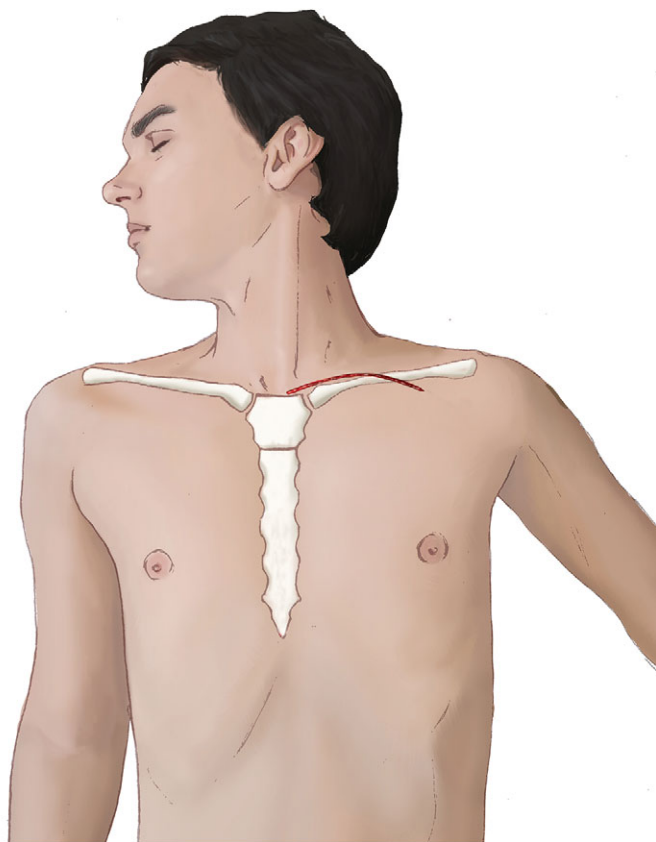


Figure 7.5 The clavicular incision begins at the sternoclavicular junction, extends over the medial half of the clavicle, and at the middle portion of the clavicle it curves downwards into the deltopectoral groove. This can be combined with a median sternotomy for improved exposure of the proximal left subclavian artery and upper mediastinal vessels.

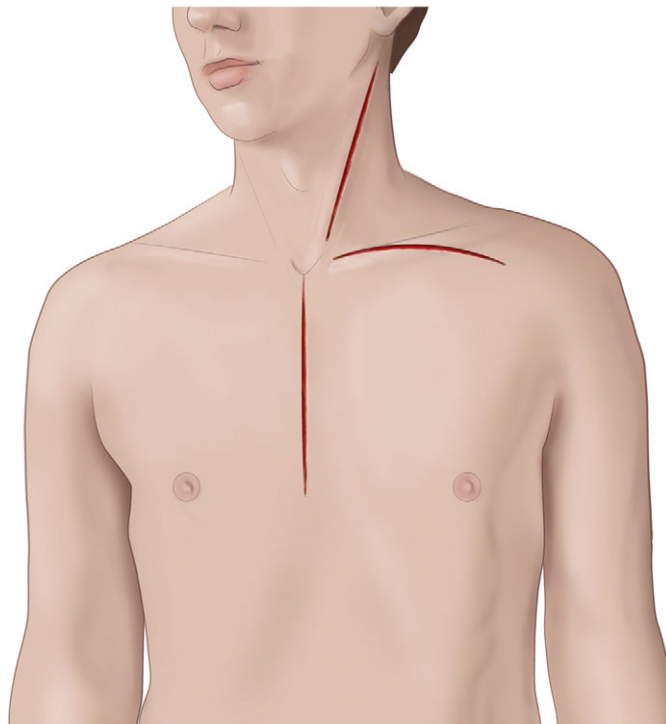


Figure 7.6 Anterior sternocleidomastoid, clavicular, and median sternotomy incisions. These incisions can be combined and extended to maximize exposure.

Pitfalls

- Airway compromise may occur after direct trauma to the larynx or trachea, or due to external compression by a large hematoma. The surgeon should be ready to perform a surgical airway. This compression can be worsened by a cervical collar; remove the collar if there is concern for airway compression.
- Never place an intravenous line in the arm on the same side as a supraclavicular injury, because of the possibility of the presence of a subclavian vessel injury.
- Air embolism must be a concern in a patient with major venous injury. To prevent this lethal complication, place the patient in the Trendelenburg position and occlude the wound with gauze.
- Always prepare the chest when bringing patients to the operating room. Injuries in the neck may track down towards the mediastinal structures, requiring a sternotomy for control and repair.
- All of the access incisions are extendable and can be combined. This will maximize exposure, and facilitate exploration and repair.
- For the esophagus and trachea, take care to avoid missing a second backwall injury, as these can be difficult to detect with a lateral incision.
- Zone 3 injuries can be very difficult to access surgically. Endovascular intervention should be considered for these injuries.

Carotid Artery and Internal Jugular Vein Injuries

Edward Kwon, Daniel Grabo, and George C. Velmahos

Surgical Anatomy

- The right common carotid artery originates from the innominate (brachiocephalic) artery. The external landmark is the right sternoclavicular joint. The left common carotid artery originates directly from the aortic arch in the superior mediastinum.
- The carotid sheath contains the common and internal carotid arteries, the internal jugular vein, and the vagus nerve. The internal jugular vein lies lateral and superficial to the common carotid artery and vagus nerve. The vagus nerve lies posteriorly, between the artery and the vein. On occasion the vagus nerve may be located anterior to the vessels.

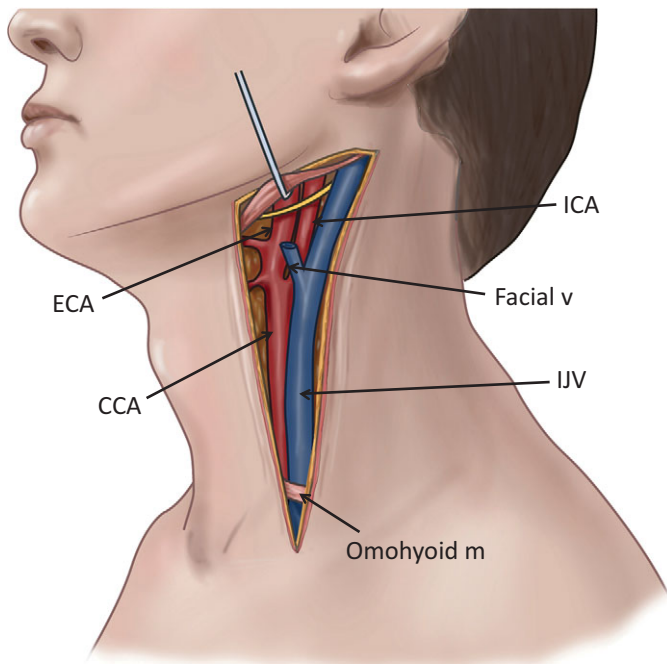


Figure 8.1 Surface anatomy and key anatomical relationships of the carotid artery.

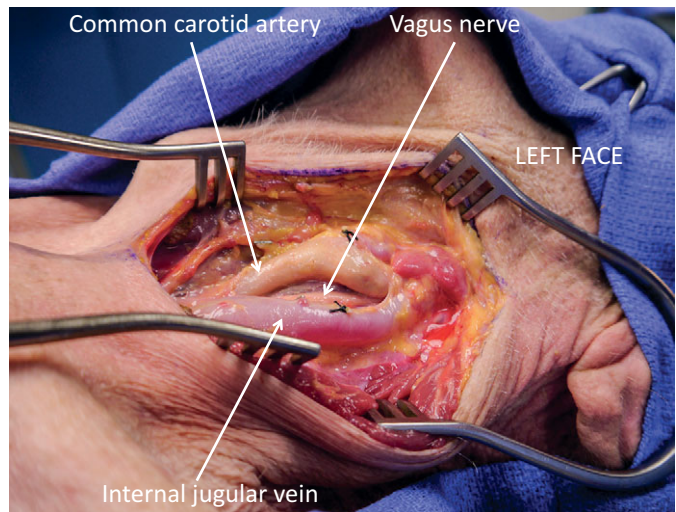


Figure 8.2 Carotid sheath contents. The carotid sheath contains the common carotid and internal carotid arteries medially, the internal jugular vein laterally, and the vagus nerve posteriorly between the vessels.

- The carotid sheath and its contents are covered superficially by the platysma, anterior margin of the sternocleidomastoid muscle, and the omohyoid muscle. Deep to the vessels are the longus colli and longus capitis muscles. Medial to the carotid sheath is the esophagus and trachea.
- At the level of the superior border of the thyroid cartilage, the common carotid artery bifurcates into the internal and external carotid arteries.
- The facial vein crosses the carotid sheath superficially to enter the internal jugular vein at the level of the carotid bifurcation.

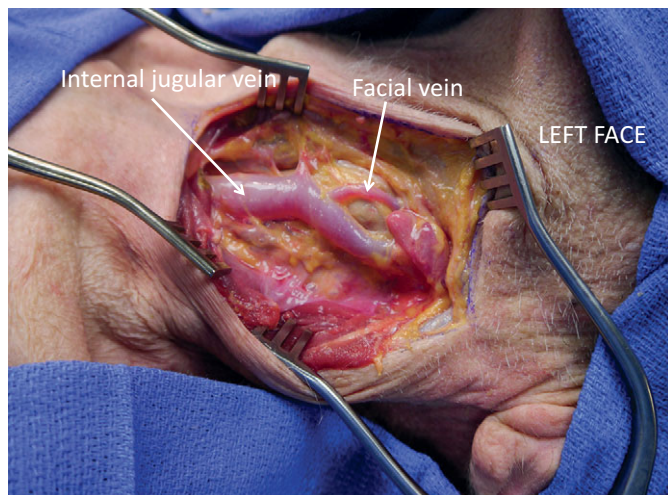


Figure 8.3 The facial vein is the anatomical landmark approximating the location of the carotid bifurcation deep to it. The facial vein is ligated and divided in order to mobilize the internal jugular vein laterally and provide exposure to the underlying carotid bifurcation.

- The external carotid artery lies medial to the internal carotid artery for the majority of their course. The first branch of the external carotid artery is the superior thyroid artery located near the carotid bifurcation.
- The internal carotid artery does not have any extracranial branches.

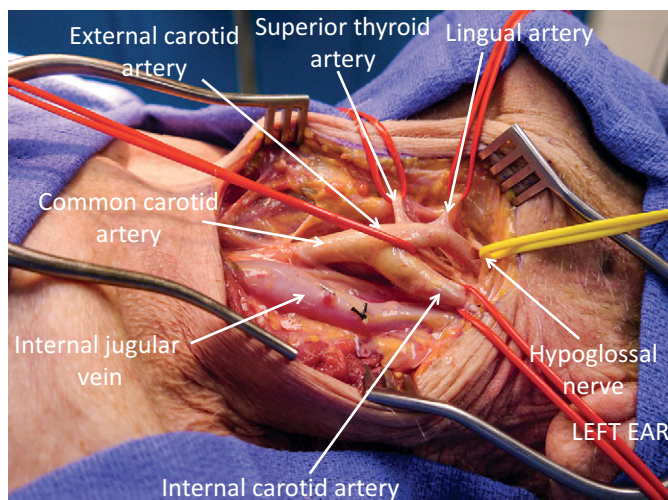


Figure 8.4 The external carotid lies medial to the internal carotid artery and gives several branches (the first branches are the superior thyroid and lingual arteries). The internal carotid artery has no extracranial branches. Note the hypoglossal nerve (yellow loop) crossing over the two arteries.

- At the level of the angle of the mandible, the internal and external carotid arteries are crossed superficially by the hypoglossal nerve (Cranial Nerve XII) and the posterior belly of the digastric muscle. The glossopharyngeal nerve (Cranial Nerve IX) passes in front of the internal carotid artery, above the hypoglossal nerve.

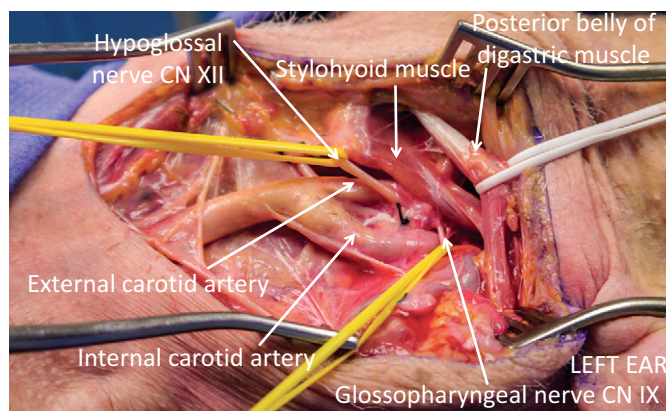


Figure 8.5 Distal carotid artery anatomy. At the angle of the mandible, the carotid arteries are crossed superficially by the hypoglossal nerve, the posterior belly of the digastric muscle, and the glossopharyngeal nerve.

- The external carotid arteries terminate in the parotid gland, where they divide into the superficial temporal and maxillary arteries.
- At the level of the skull base, the internal carotid arteries cross deep and medial to the external carotid arteries to enter the carotid canal behind the styloid process.

General Principles

- A preoperative neurologic examination should always be performed and documented.
- Patients with neurologic deficits secondary to carotid artery injury have a poor prognosis. If the diagnosis is made early (within 4–6 hours) revascularization should be performed. Delayed revascularization can convert an ischemic infarct into a hemorrhagic infarct, leading to increased morbidity, and should therefore be avoided.
- If technically possible, all common and internal carotid artery injuries should be repaired, as ligation is associated with a significant risk of stroke. Ligation may be considered in the comatose patient with delayed operation (>6 hours from injury) or if there is uncontrollable hemorrhage. Temporary shunt placement is a preferred method of damage control for these injuries.
- Prophylactic shunting of the common or internal carotid arteries should be considered intraoperatively in patients requiring reconstruction with grafts.
- Minor carotid injuries, such as small intimal tears, may be managed nonoperatively with antithrombotic therapy and imaging to document resolution.
- Select patients with extremely proximal or distal carotid injuries may be best managed with angiographically placed stents.
- The external carotid artery can be ligated without significant sequelae.
- Systemic heparinization (100 u/kg) should be considered in patients with no other injuries. Alternatively, heparin saline

solution (5,000 units in 100 mL normal saline) can be injected locally, both proximal and distal into the injured vessel.

- Unilateral internal jugular vein injuries can be repaired if the patient's condition allows, and there is no significant stenosis (<50%). However, unilateral ligation is well tolerated. If there are bilateral internal jugular vein injuries, at least one vein should be repaired.
- Vascular repairs should be protected in the presence of tracheal or esophageal injuries with interposed tissue, usually the strap muscles.

Special Surgical Instruments

- Complete vascular tray, Fogarty catheters, a carotid shunt, and rummel tourniquets. As exposure of the mediastinal segment of the carotid arteries or internal jugular veins may be required, a chest tray, sternal saw, and sternal retractor should always be available. One percent of lidocaine should also be readily available for possible injection of the carotid body if necessary, as well as prosthetic graft materials (PTFE or Dacron) in the event that reconstruction requires a conduit.
- Headlights and surgical loupes are strongly recommended.

Positioning

- The patient is positioned supine on the operating room table, with adduction of the ipsilateral arm, or bilateral arms if the neck injuries are bilateral.
- The neck should be slightly extended and the head turned to the contralateral side. If possible, elevation of the shoulders with a shoulder roll will facilitate extension of the neck.
- The patient should be prepped to include the entirety of the neck from the earlobes to the base of the skull, and extending to the inferior aspect of the mandible, down to the chest. The chest should be included to facilitate proximal control. The groins should also be included in the field, in case a saphenous vein graft is required.

Incisions

- The standard incision for exposure to the cervical carotid arteries and internal jugular veins is a longitudinal incision along the anterior border of the sternocleidomastoid

muscle, extending from the suprasternal notch to just below the mastoid process.

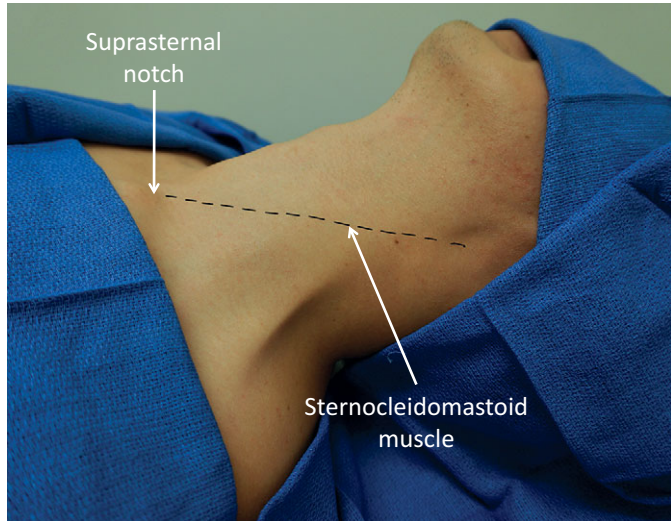


Figure 8.6 The patient is positioned with the neck extended and head rotated contralaterally. A roll under the shoulders may be helpful to achieve maximal extension of the neck. The standard incision is placed along the anterior border of the sternocleidomastoid muscle from the suprasternal notch to the mastoid process.

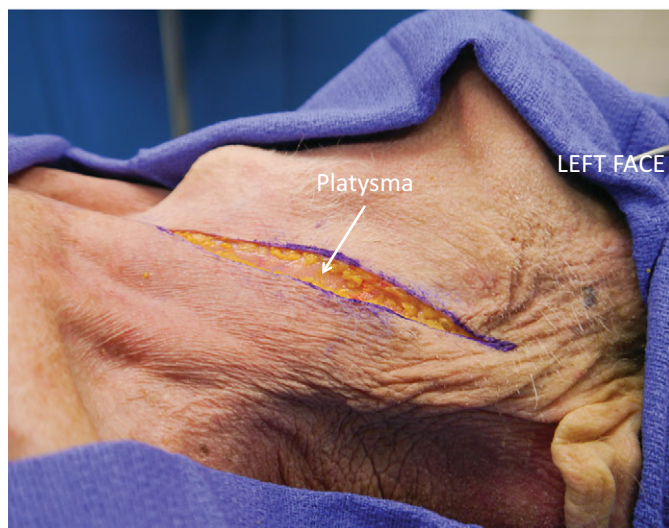
- For proximal common carotid artery or internal jugular vein injuries, the combination of a sternocleidomastoid incision and median sternotomy provides the optimal exposure (see [Chapter 16](#), Thoracic Vessels).

Operative Technique

Exposure

- A longitudinal incision is made along the anterior border of the sternocleidomastoid muscle, from the mastoid process to the suprasternal notch. The incision is carried through the platysma to expose the anterior border of the sternocleidomastoid muscle.
- The anterior border of the sternocleidomastoid muscle is then dissected free along its length and retracted laterally. At the upper part of the incision, the accessory nerve (Cranial Nerve XI) enters the sternocleidomastoid muscle and care should be taken to avoid injury.

(a)



(b)

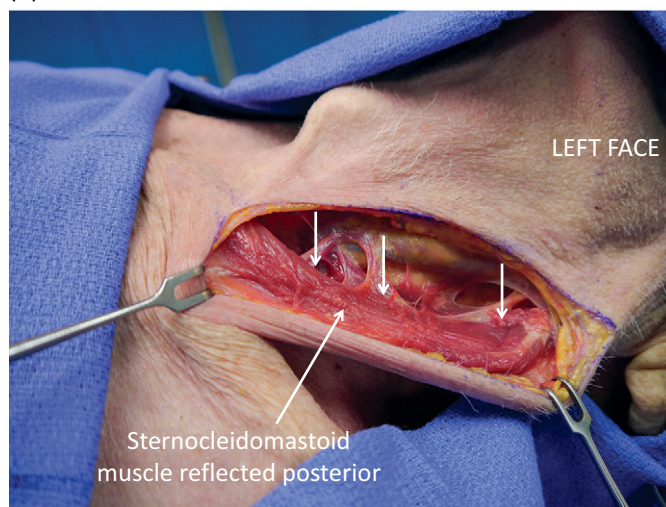
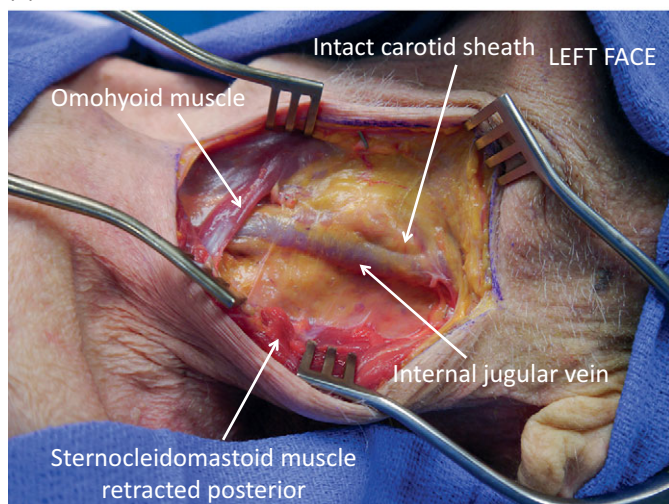


Figure 8.7 (a) The skin is incised along the anterior border of the sternocleidomastoid muscle to expose the underlying platysma. (b) The sternocleidomastoid is dissected along its anterior border and retracted laterally. Small branches of the external carotid artery (white arrows) are ligated and divided to adequately mobilize the sternocleidomastoid muscle and expose the carotid sheath.

- The carotid sheath is now visible and is incised along its length. If more proximal exposure is required, the omohyoid muscle may be divided.

(a)



(b)

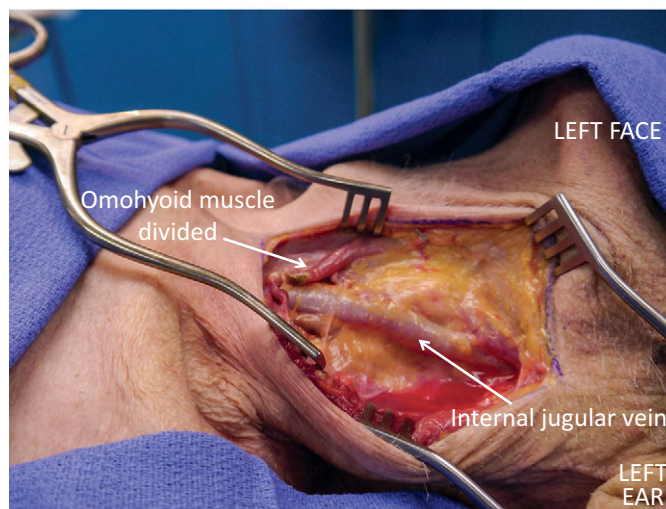


Figure 8.8 (a) Carotid sheath and omohyoid. The sternocleidomastoid muscle is retracted posterior to reveal the underlying carotid sheath and its contents. The omohyoid muscle at the inferior border of the incision may be divided if more proximal exposure is required. (b) Exposure to the proximal common carotid artery and internal jugular vein may be improved with division of the omohyoid muscle.

- The contents of the carotid sheath are now exposed. The internal jugular vein is then mobilized and retracted laterally, and the common carotid artery is retracted anteromedially. The vagus nerve, located posteriorly between the vessels, is identified and protected. Vessel loops are placed around the artery, vein, and nerve. For exposure of the carotid bifurcation, the facial vein is identified and ligated.

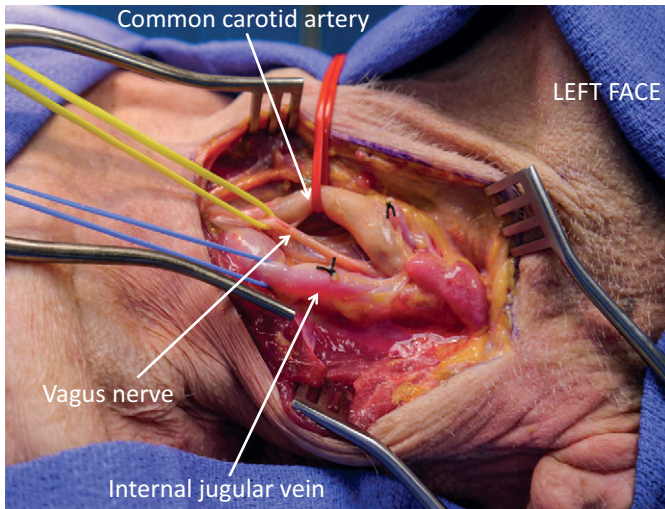


Figure 8.9 Carotid sheath contents. The common carotid artery and internal jugular vein are identified and looped. The vagus nerve is identified posterior and between the vessels (yellow loop).

- During dissection of the carotid bifurcation, the carotid body may be stimulated causing hemodynamic instability (hypotension and bradycardia). If this is encountered, the carotid body may be injected with 1% lidocaine. The external and internal carotid arteries are then dissected and isolated using vessel loops.

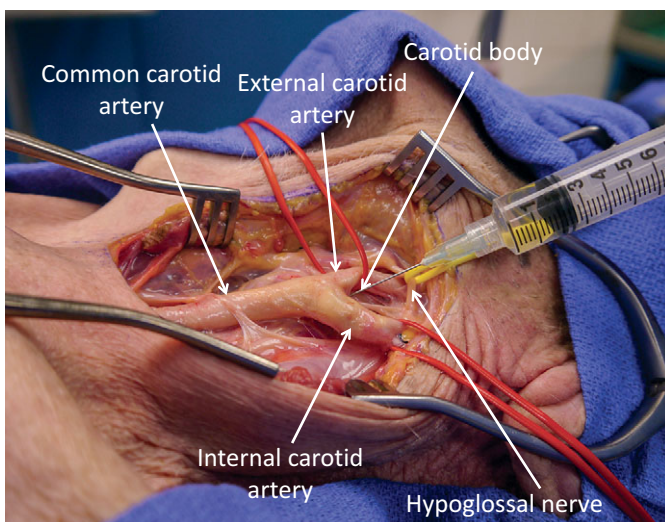
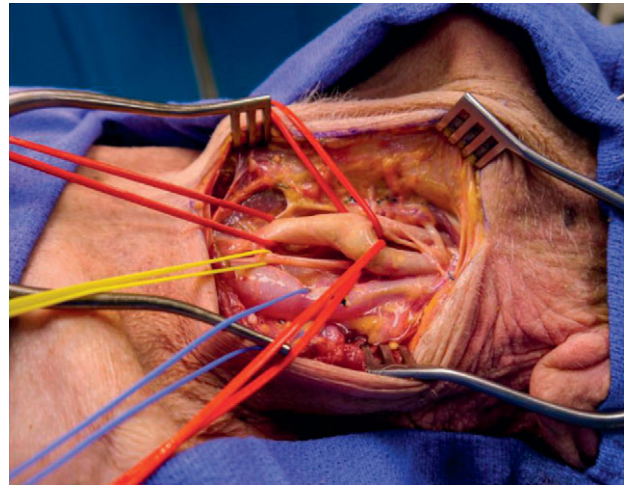


Figure 8.10 Carotid body injection. During the dissection of the carotid bifurcation, the carotid body may become stimulated causing hypotension and bradycardia. If this situation is encountered, 1% lidocaine may be injected into the carotid body located in the crotch of the bifurcation.

- The ansa cervicalis should be visible anterior to the carotid bifurcation and can be followed to the hypoglossal nerve. Once the hypoglossal nerve (Cranial Nerve XII) is identified and protected, the ansa cervicalis may be divided, if necessary, for exposure.

(a)



(b)

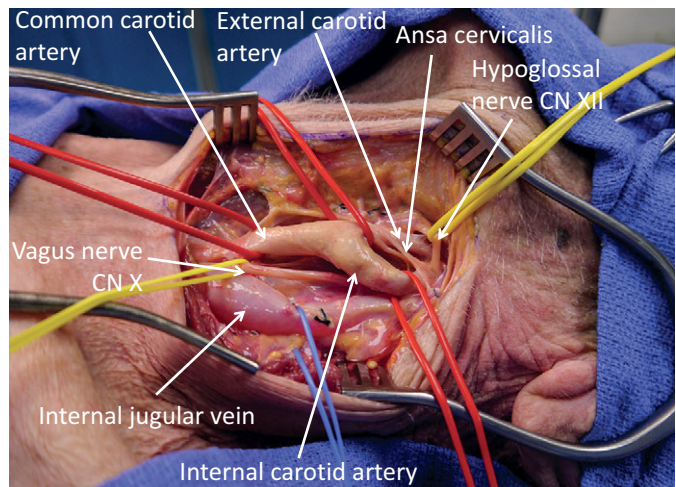


Figure 8.11 (a) The carotid bifurcation is carefully dissected and the common, internal and external carotid arteries are isolated and looped. Note that the external carotid artery is medial to the internal carotid artery at the bifurcation. (b) Hypoglossal nerve and ansa cervicalis. The ansa cervicalis overlies the carotid bifurcation and may be followed to identify the hypoglossal nerve. The hypoglossal nerve crosses the internal and external carotid arteries distal to the bifurcation.

- Exposure of the distal internal carotid artery is challenging and may require techniques, such as subluxation of the mandible and possibly mandibular osteotomy.
 - Subluxation of the mandible may be achieved by grasping the lower teeth with two hands and pulling the mandible downward and anteriorly. An assistant may hold the jaw in position as the surgeon exposes the vessel.

- Exposure to internal carotid at the base of the skull is achieved by extending the surgical incision posteriorly around the ear and dividing the posterior belly of the digastric, stylohyoid, stylopharyngeus, and styloglossus muscles. The styloid process is then removed. Care should be taken to avoid injury to the glossopharyngeal nerve (Cranial Nerve IX) deep to the posterior digastric and along the stylohyoid muscle.

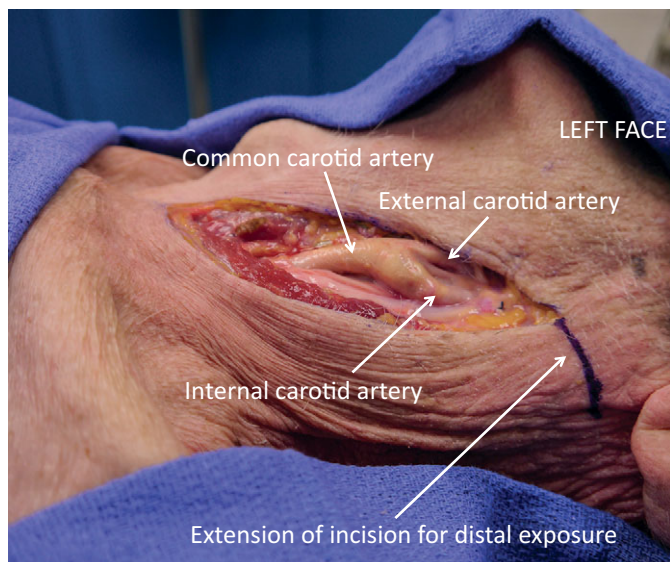


Figure 8.12 Left distal carotid artery exposure. To expose the carotid artery and internal jugular vein close to the base of the skull, the incision is extended in a postauricular fashion and the mandible is then subluxed and wired or held by an assistant to maintain subluxation.

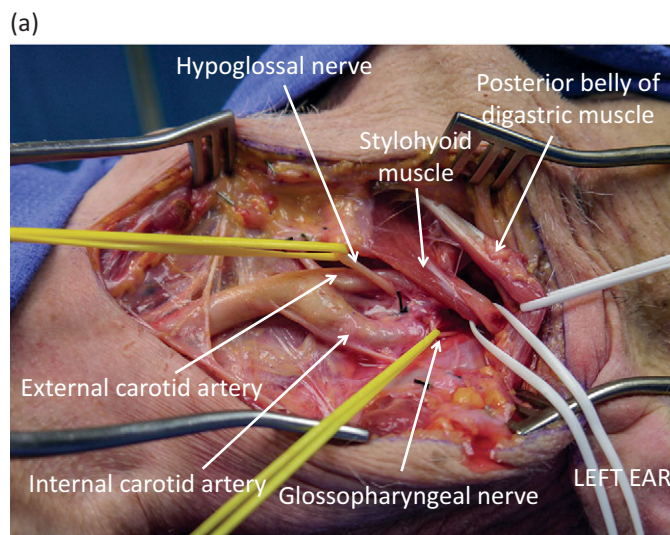


Figure 8.13 (a) Distal carotid exposure. Subluxation of the mandible is achieved allowing more distal exposure of the internal carotid artery. The posterior belly of the digastric muscle and stylohyoid muscles overlie the distal internal carotid artery. Deep to the muscle lies the glossopharyngeal nerve. **(b)** Division of the posterior belly of the digastric muscle. Care should be taken to avoid injury to the underlying glossopharyngeal nerve during division.

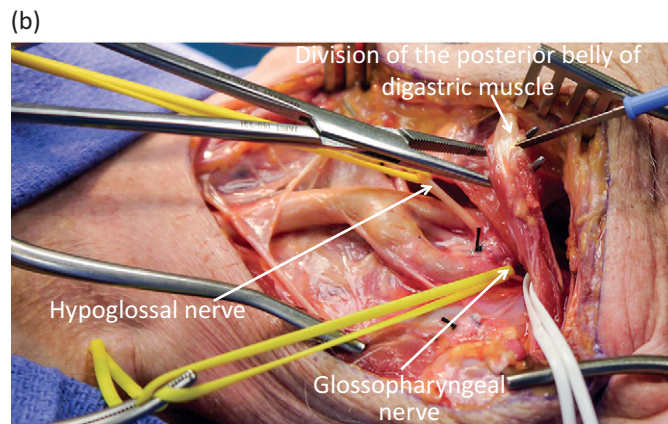


Figure 8.13 (cont.)

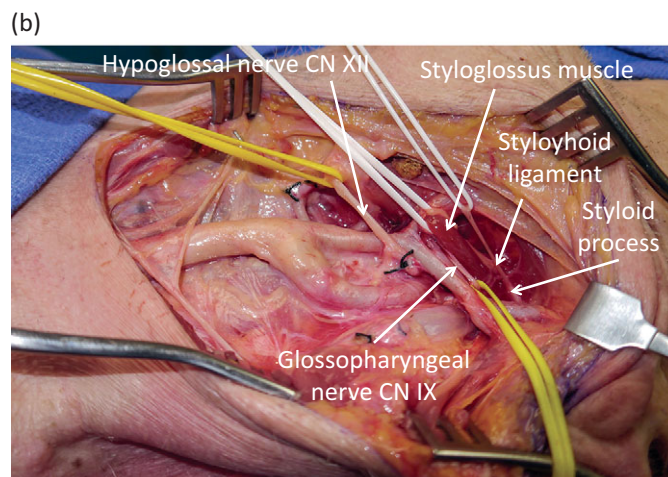
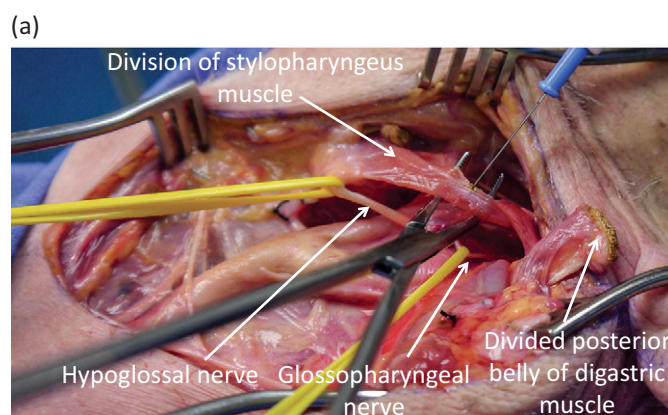


Figure 8.14 (a) Division of the stylopharyngeus. The stylopharyngeus muscle is divided to continue exposure to the distal carotid artery. Care should be taken to avoid injury to the underlying glossopharyngeal nerve. **(b)** Once the stylopharyngeus is divided, the underlying styloglossus and stylohyoid ligaments are identified and divided. Care should be taken to avoid injury to the underlying glossopharyngeal nerve.

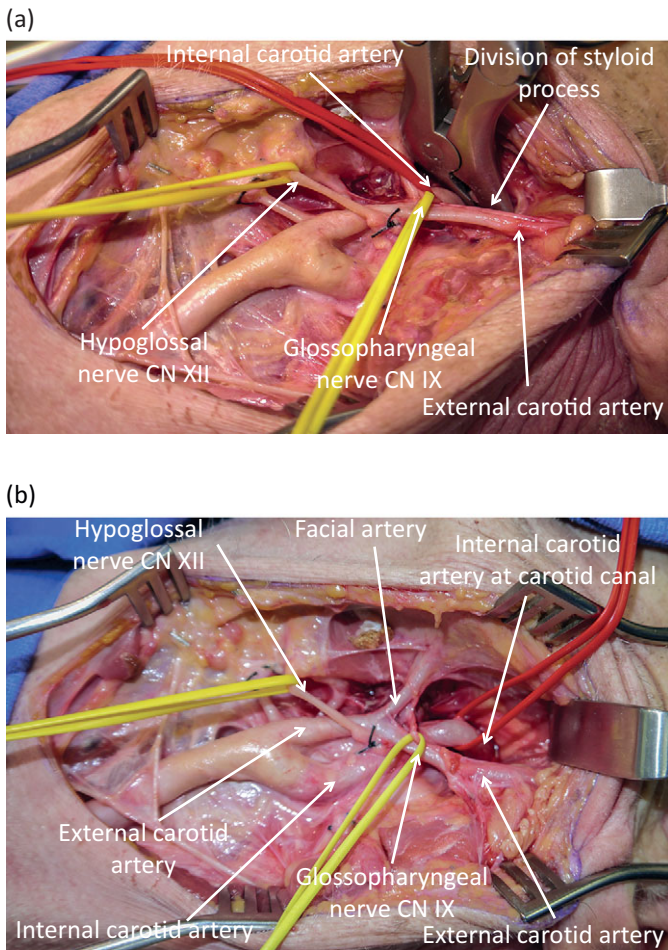


Figure 8.15 (a) Styloid process. Once the muscles are divided, the styloid process is divided with a rongeur to gain exposure to the internal carotid artery at the carotid canal. (b) Internal carotid artery at carotid canal. With the jaw subluxed and the styloid muscles and process divided, the internal carotid artery is exposed as it enters the carotid canal. Note the course of the internal carotid as it crosses deep and medial to the external carotid artery. The termination of the external carotid artery into the parotid gland is also well exposed.

- Exposure to proximal cervical carotid or jugular injuries may require the addition of a sternotomy to the standard sternocleidomastoid incision. This technique is described in the chapter on mediastinal vascular injuries.

Repair

- Small carotid artery injuries without significant tissue loss (usually secondary to knife wounds) may be repaired by mobilization and primary suturing with 5-0 monofilament nonabsorbable suture. The intima should be inspected through the injury to ensure backwall integrity prior to closure.
- Carotid shunts should be utilized during more complex repairs to protect against ischemic stroke.

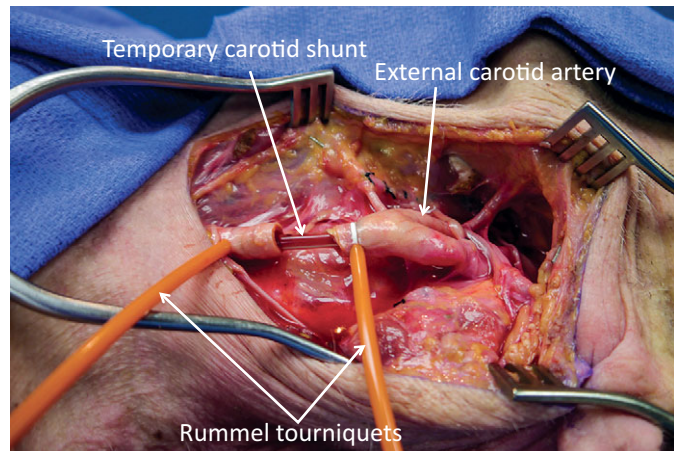


Figure 8.16 Temporary carotid shunt. A temporary carotid shunt should be used for repairs of the carotid artery more complex than lateral arteriorrhaphy. The shunt may be secured with rummel tourniquets, allowing continued cerebral perfusion during reconstruction to prevent ischemia.

- If the repair is not possible without causing stenosis, a patch angioplasty can be performed using either a vein patch (saphenous vein or external jugular vein) or prosthetic material (Dacron, PTFE, bovine pericardium), sutured in a running continuous fashion circumferentially around the defect using a 5-0 monofilament nonabsorbable suture.
- For destructive injuries with significant tissue loss (usually secondary to firearm injuries or blunt trauma), an interposition graft with either reverse saphenous vein or prosthetic material (Dacron, PTFE) should be used. Alternatively, transposition of the external carotid artery may be possible in select circumstances to reconstruct the internal carotid artery injury.

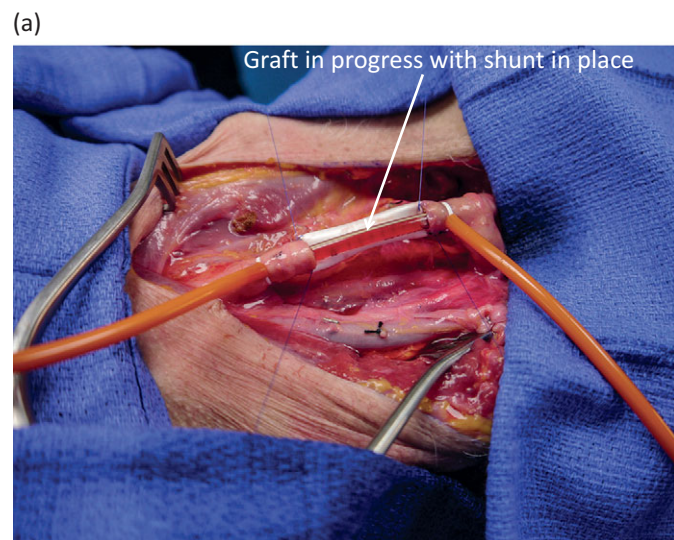
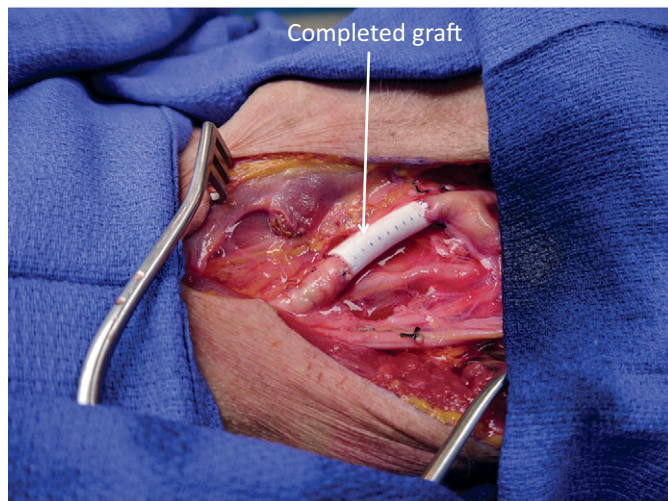
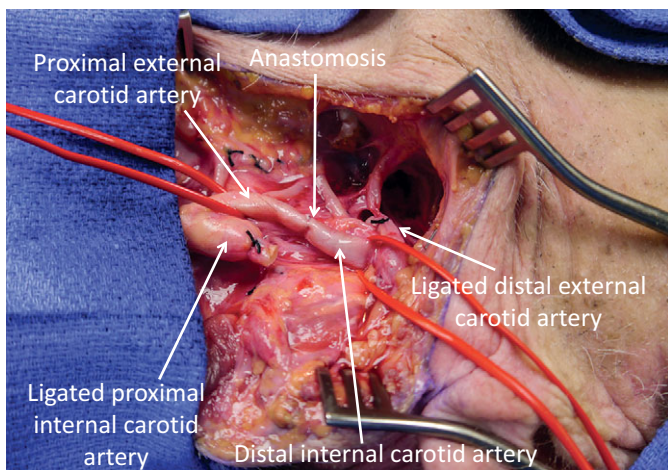
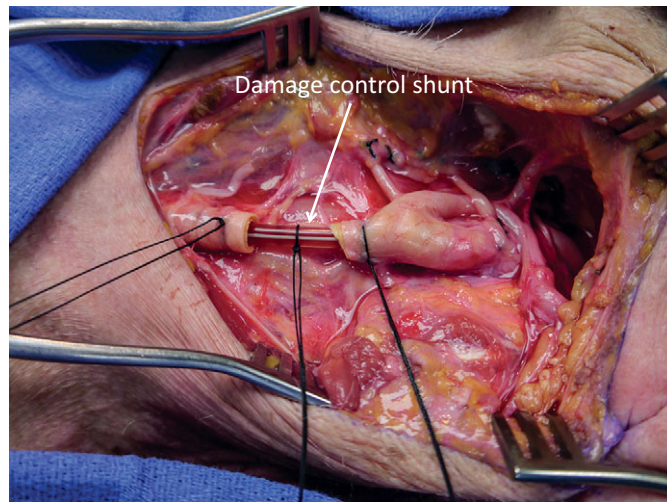


Figure 8.17 (a) Graft reconstruction with temporary shunt. A temporary shunt is placed in the lumen of the injured vessel to maintain cerebral perfusion, while a graft is sutured in place. Note that the same technique may be used during a patch angioplasty reconstruction. (b) Interposition graft. Once the graft is anastomosed, the temporary shunt is removed. Possible conduits include reverse saphenous vein, PTFE, and Dacron.

(b)

**Figure 8.17** (cont.)**Figure 8.18** External to internal carotid transposition. In rare circumstances, transposition of the external carotid artery proximal to the injury to the distal internal carotid artery may be used to reconstruct the injured vessel.

- If the patient is not stable enough to undergo definitive repair of the carotid vessels, a carotid shunt may be placed to maintain cerebral blood flow during the resuscitative period with delayed reconstruction.

**Figure 8.19** Damage control carotid shunt. The shunt is secured with silk ties around the proximal and distal arterial segments, as well as the shunt itself, to prevent migration of the shunt.

- Internal jugular vein injuries may be repaired, if technically feasible and repair does not result in stenosis greater than 50%. If there is unilateral injury and the patient is unstable, then ligation is appropriate. If there are bilateral injuries to the internal jugular veins, then attempts should be made to repair one side, if at all possible.

Wound Closure

- The wound should be closed in layers with reapproximation of the sternocleidomastoid muscle, platysma, and skin over a closed suction drain.

Tips and Pitfalls

- In patients with neurologic deficits secondary to carotid artery injury, revascularization should be performed within 4–6 hours of the injury. Delayed revascularization after this time period can convert an ischemic brain infarct into a hemorrhagic infarct.
- Subluxation of the mandible is not difficult and may improve the exposure of the distal internal carotid artery by an additional 2–3 cm.
- Distal control of internal carotid injuries at the level of the base of the skull may require balloon catheter tamponade and thrombosis or ligation as the definitive management, if not possible to revascularize distally secondary to anatomical barriers.

Subclavian Vessels

Demetrios Demetriades and Jennifer A. Smith

Surgical Anatomy

- On the right side, the subclavian artery originates from the innominate (brachiocephalic) artery, which branches into the right subclavian and right common carotid arteries. On the left side, it originates directly from the aortic arch. In some individuals, the left subclavian artery may have a common origin with the left common carotid artery.
- The subclavian artery courses laterally, passing between the anterior and middle scalene muscles. This is in contrast to the subclavian vein, which is located superficial to the anterior scalene muscle.

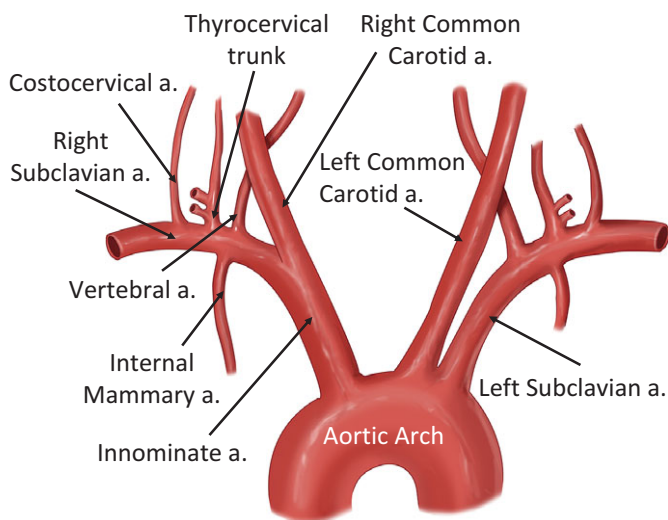


Figure 9.1 The right subclavian artery originates from the innominate artery and the left subclavian artery originates directly from the aortic arch. Note the major branches of the subclavian artery.

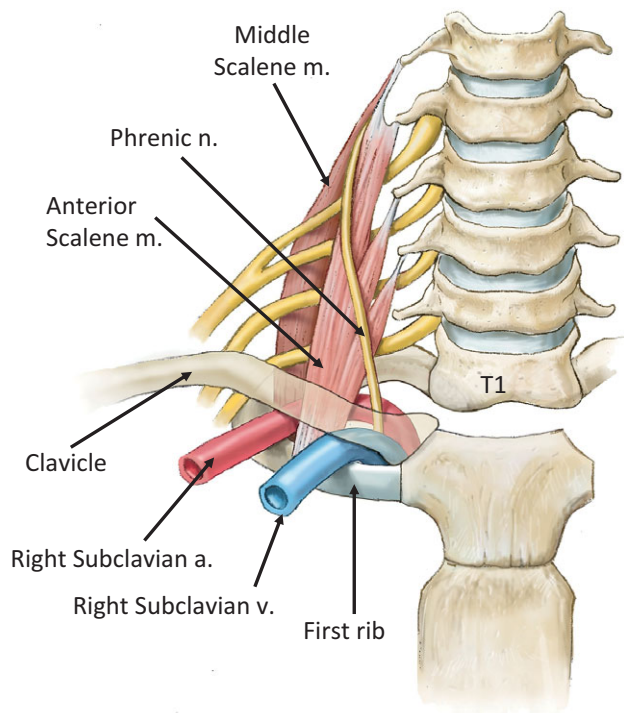


Figure 9.2 The subclavian vein is anterior to the anterior scalene muscle and the artery is posterior. Notice the phrenic nerve on the anterior surface of the anterior scalene muscle. The brachial plexus is between the anterior and middle scalene muscles.

- The subclavian artery is divided into three parts on the basis of its relationship to the anterior scalene muscle. The first part extends from its origin to the medial border of the anterior scalene muscle, coursing deep to the sternocleidomastoid and the strap muscles. It gives rise to the vertebral, internal mammary (internal thoracic), and thyrocervical arteries. The second part lies deep to the anterior scalene muscle and superficial to the upper and middle trunks of the brachial plexus. Here, it gives rise to the costocervical artery (on the left side, costocervical artery comes off the first part of the subclavian artery). The third part is located lateral to the anterior scalene muscle, and courses over the lower trunk of the brachial plexus, usually giving rise to the dorsal scapular artery, although its branches are not constant.

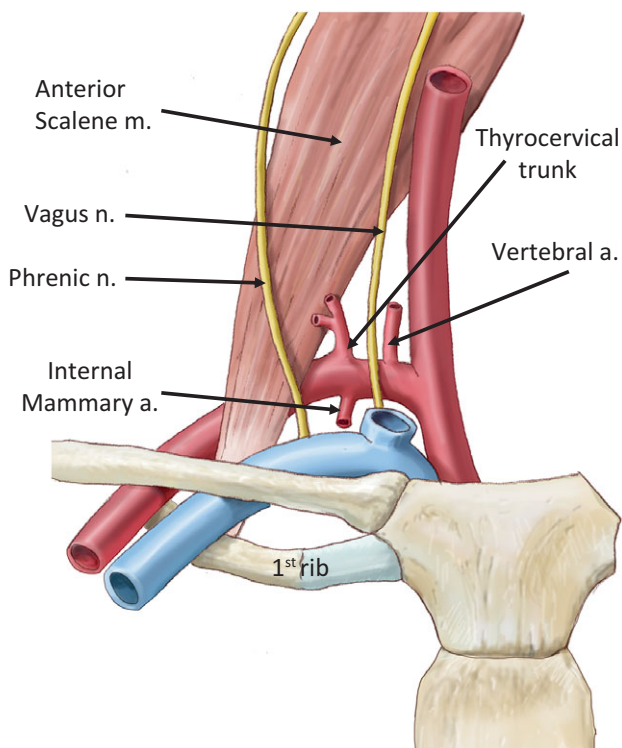


Figure 9.3 Anatomy and branches of the right subclavian artery. Note the three branches of the first part of the artery (vertebral and thyrocervical arteries coursing superiorly, and the internal mammary artery coursing inferiorly). The phrenic nerve crosses over the anterior scalene muscle and lies lateral to the internal mammary artery. The vagus nerve is medial to the internal mammary artery.

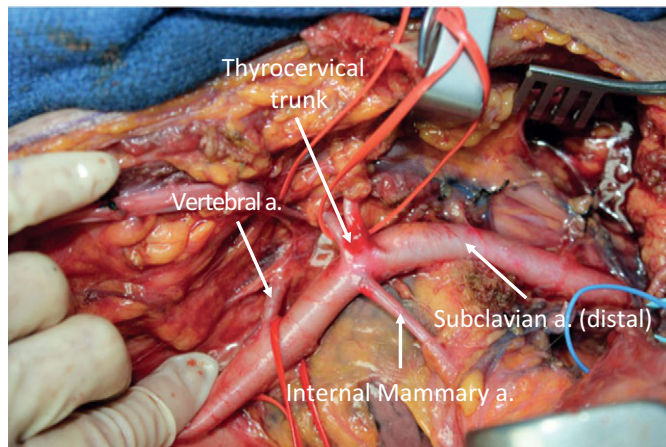


Figure 9.4 Branches of the first part of the left subclavian artery, shown after division of the anterior scalene muscle: vertebral a., internal mammary a., and thyrocervical trunk.

- The subclavian artery continues as the axillary artery, as it passes over the first rib. The external landmark for this transition is the lower border of the middle of the clavicle. The external landmark for the axillary artery is a curved line from the middle of the clavicle to the deltopectoral groove.
- The subclavian vein is the continuation of the axillary vein and originates at the level of the outer border of the first rib. It crosses in front of the anterior scalene muscle, and at the medial border of the muscle, it joins the internal jugular vein to form the innominate (brachiocephalic) vein. The left thoracic duct drains into the left subclavian vein at its junction with the left internal jugular vein. The right thoracic duct drains into the junction of the right subclavian vein and right internal jugular vein.

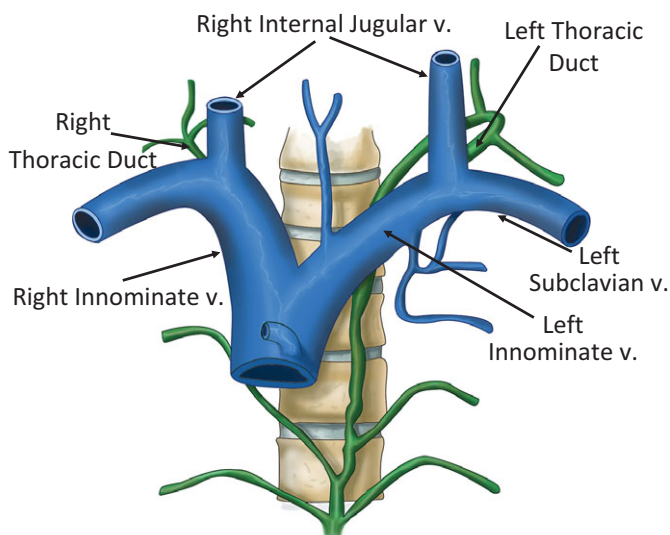


Figure 9.5 Anatomical relationship between the subclavian veins and the thoracic ducts. The ducts drain at the posterior junctions of the subclavian veins with the internal jugular veins.

- The vagus nerve is in close proximity to the first part of the subclavian artery and it lies medial to the internal mammary artery. On the right side, it crosses in front of the artery and immediately gives off the recurrent laryngeal nerve (RLN), which loops behind the subclavian artery and ascends behind the common carotid artery into the tracheoesophageal groove. On the left side, the vagus nerve travels between the common carotid and subclavian arteries and immediately gives rise to the RLN, which loops around the aortic arch and ascends into the tracheoesophageal groove.

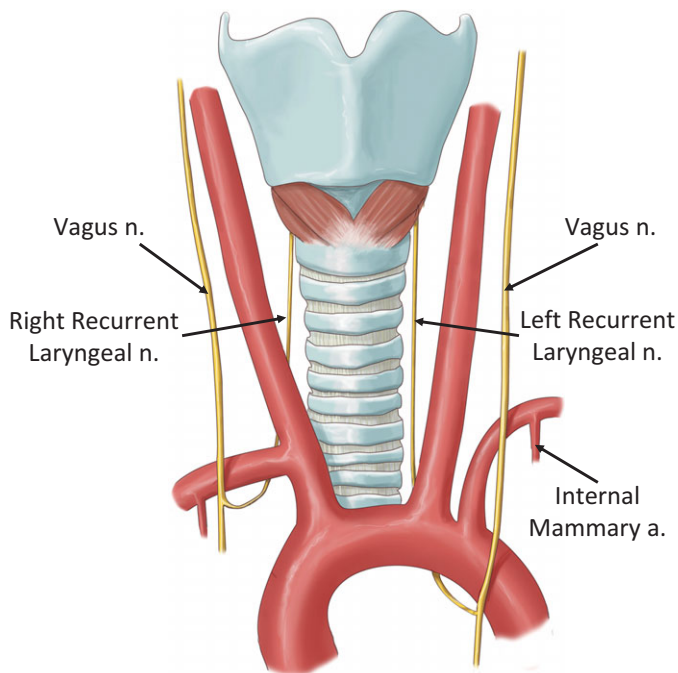


Figure 9.6 Anatomical relationship between the vagus and recurrent laryngeal nerves and the subclavian artery. The vagus nerve crosses over the first part of the subclavian artery, medial to the internal thoracic artery. On the left, the recurrent nerve loops around the aortic arch, and on the right, around the subclavian artery.

General Principles

- Ligation of the subclavian artery is associated with a high incidence of limb loss and should not be performed. In critically unstable patients, temporary shunting with delayed reconstruction should be considered.

- Vascular reconstruction usually requires a 6 mm or 8 mm polytetrafluoroethylene graft. A saphenous vein graft may be possible in some cases, if the size match is adequate.

Special Surgical Instruments

The surgeon should have readily available a standard vascular tray, sternal saw, Gigli saw, Finochietto retractor, periosteal elevator, Doyen raspatory and a selection of Fogarty catheters.

Positioning

The patient is placed supine on the operating room table, with the ipsilateral arm abducted to 30°. Avoid excessive abduction. The patient's head should be turned to the contralateral side. Ensure that the patient is prepped from the chin to the knees, and include the entire ipsilateral arm within the surgical field.

Incisions

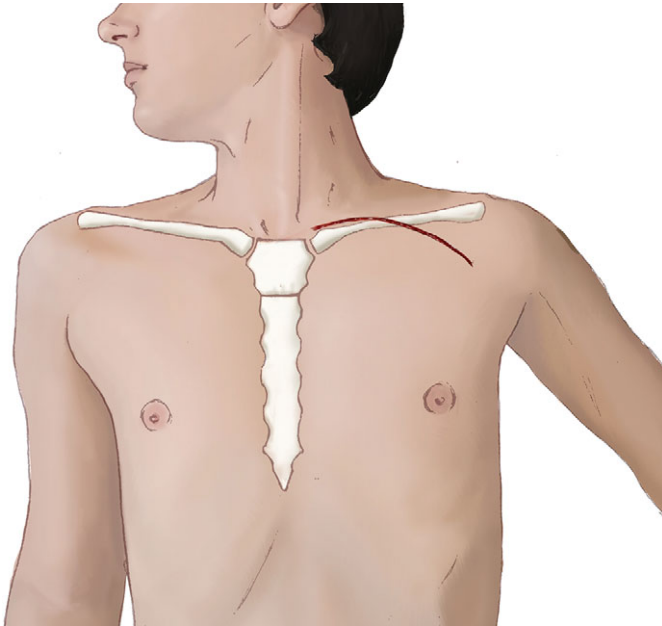
- Depending on the site of the subclavian vascular trauma (left or right, proximal or distal) and on surgeon preference, a variety of incisions and exposures can be used. The most common being the clavicular incision with or without a median sternotomy, and the trap-door incision.
- Generally, for injuries to the middle or lateral part of the subclavian vessels, a clavicular incision provides good exposure. For more proximal injuries, the clavicular incision can be combined with a median sternotomy, facilitating excellent exposure of both the left and right subclavian arteries.
- For proximal injuries on the left side, classically a “trap-door” incision has been described; however, it does not improve surgical exposure and is associated with greater postoperative morbidity.
- In rare cases, if the injury is located at the mid or distal subclavian artery, exposure can be obtained through a supraclavicular incision made directly over the site of injury. The proximal and distal exposures are severely limited, however, and not generally recommended.

Exposure through a Clavicular Incision

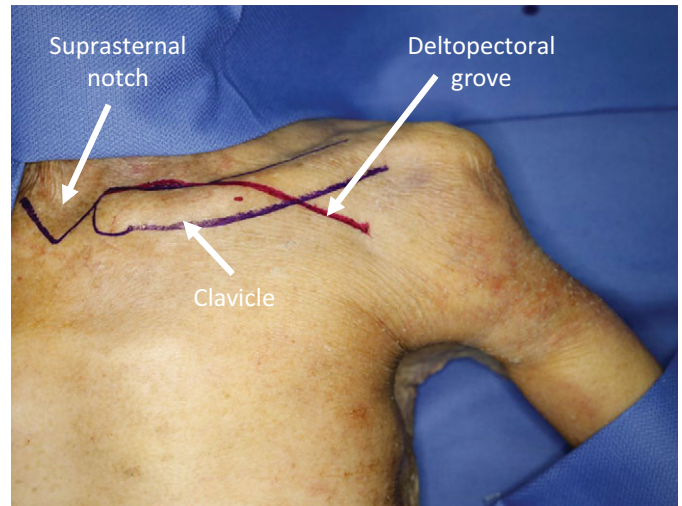
- This is the preferred starting incision and provides good exposure of the second and third parts of the subclavian

artery. It begins at the sternoclavicular junction, extends over the medial half of the clavicle, and at the middle portion of the clavicle, it curves downward into the deltopectoral groove.

(a)



(b)



(c)



Figure 9.7 (a, b, and c) Patient positioning and clavicular incision for surgical exposure of the left subclavian artery. The head is turned toward the contralateral side and the ipsilateral arm is abducted to 30°. The clavicular incision begins at the sternoclavicular junction, extends over the medial half of the clavicle, and at the middle of the clavicle, it curves downward into the deltopectoral groove. The axillary vessels are under this groove.

- Each of the muscles attached to the medial half of the clavicle (platysma and clavicular head of the sternocleidomastoid muscle superiorly, pectoralis major and subclavius muscles inferiorly) are

detached using a combination of cautery, periosteal elevation and the Doyen raspatory. The proximal half of the clavicle is now exposed and stripped of all muscular attachments.

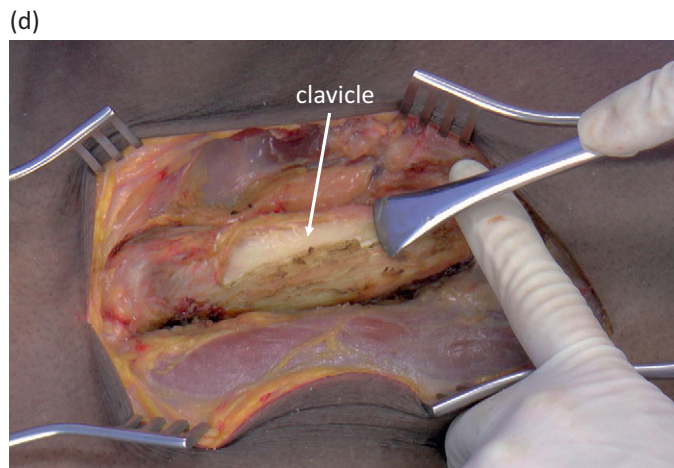
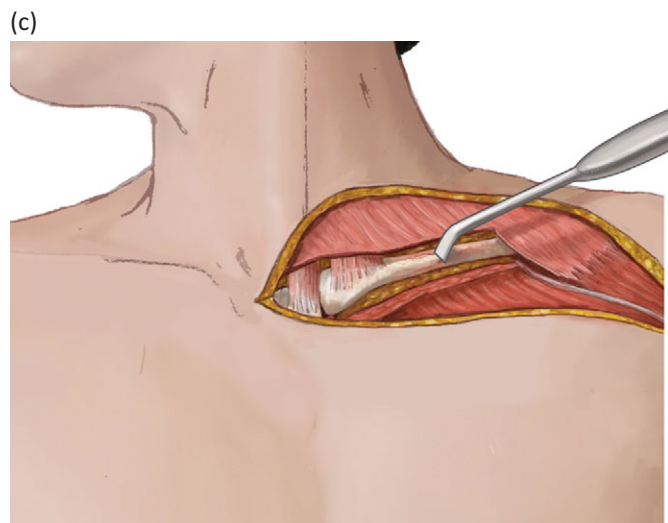
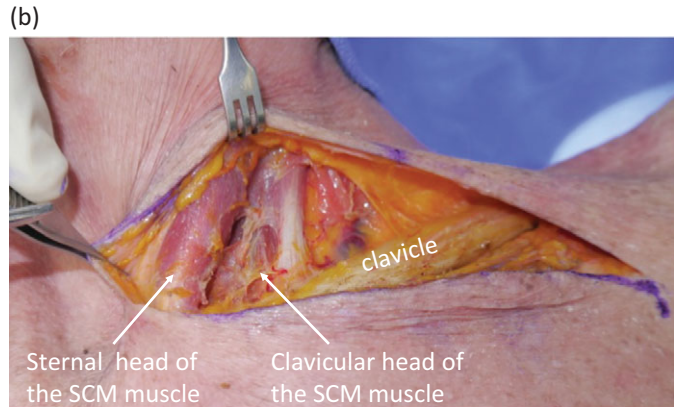
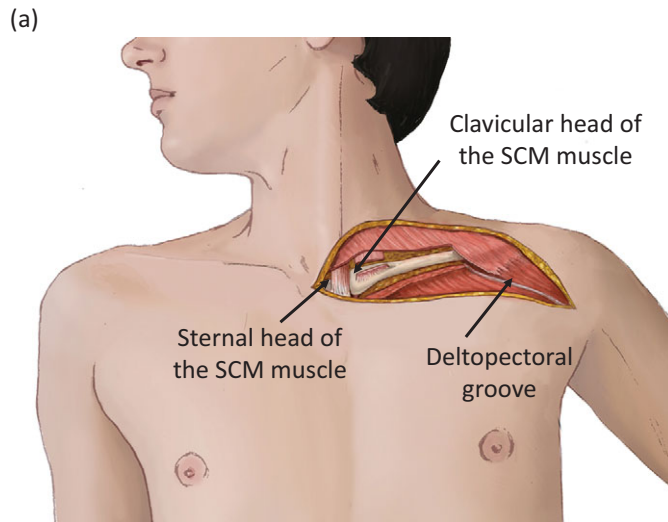
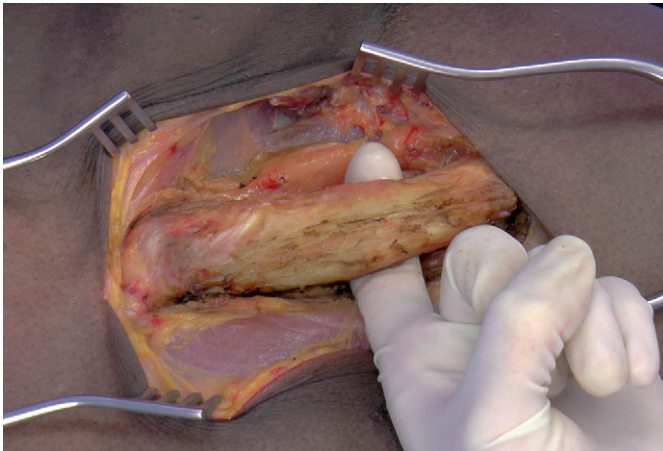


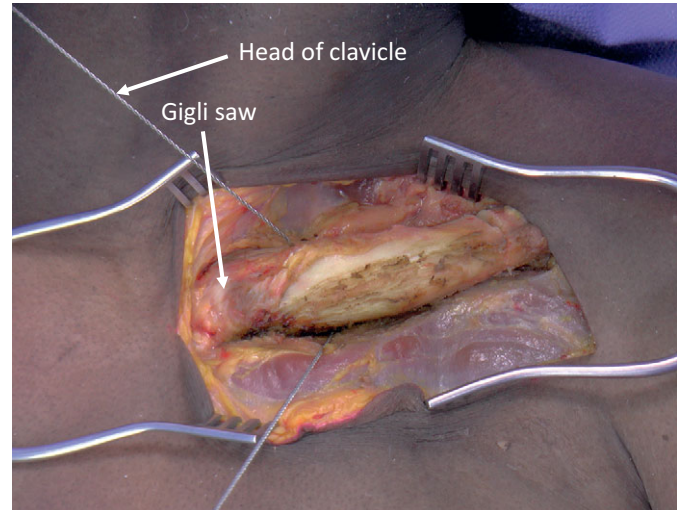
Figure 9.8 (a, b) Subclavian vascular exposure through a clavicular incision. All the muscles attached to the medial half of the clavicle (platysma and clavicular head of the SCM superiorly, and pectoralis major and subclavius inferiorly) are divided, using cautery and periosteal elevation. Note the deltopectoral groove, under which are the axillary vessels. (c, d) The periosteal elevator is used to free the clavicle from its muscle attachments.

- The subclavian vessels lie deep to the clavicle, and their exposure requires the dislocation, division, or excision of the clavicle.
 - The fastest approach is division of the clavicle with the Gigli saw, close to the sternoclavicular junction. At the end of the procedure, the anatomic integrity of the clavicle can be restored by wiring together the divided ends.
 - Disarticulation at the sternoclavicular joint is another option, but it takes significantly longer than division of the clavicle.
 - Excision of the medial half of the clavicle is also an acceptable option. It does not result in any functional disability, but the cosmetic results are inferior to clavicular reconstruction.
 - In clavicle-sparing procedures, the clavicle is grasped with a towel clamp and retracted upwards or downwards to expose the underlying tissues.

(a)



(b)



(c)

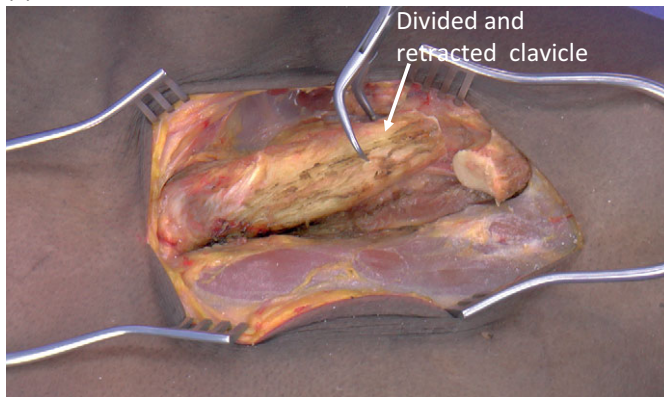


Figure 9.9 (a) The medial part of the clavicle is freed from all muscle attachments. (b) The clavicle is divided with a Gigli saw, close to the sternoclavicular junction. (c) The clavicle is retracted and the underlying tissues are exposed (circle). These fatty tissues need to be dissected in order to identify the vessels.

- The subclavian vessels, especially the artery, lie deep under the clavicular bed, and their identification requires extensive dissection of the surrounding tissues. The vein is located superficial and inferior to the artery and is the first vessel to come into view. The artery is significantly deeper than most surgeons think.

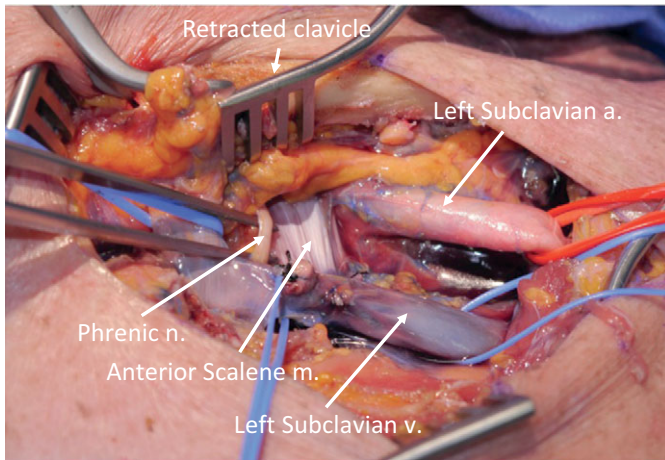


Figure 9.10 Exposure of the left subclavian vessels after division and superior retraction of the clavicle. The subclavian vein is anterior to the anterior scalene muscle and the artery is posterior. Note the phrenic nerve crossing over the muscle.

- Exposure of the first and second part of the artery requires division of the strap muscles and the anterior scalene muscle. The phrenic nerve, which lies anterior to the anterior scalene muscle, should be identified and preserved.

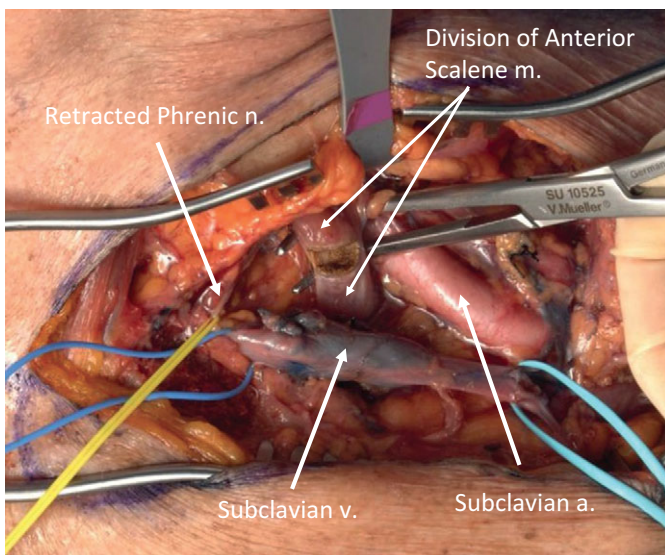
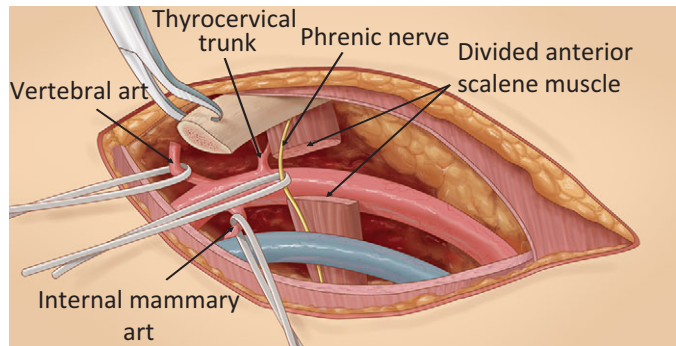


Figure 9.11 The anterior scalene muscle is divided to expose the proximal subclavian artery. The phrenic nerve is retracted and protected (yellow loop).

(a)



(b)

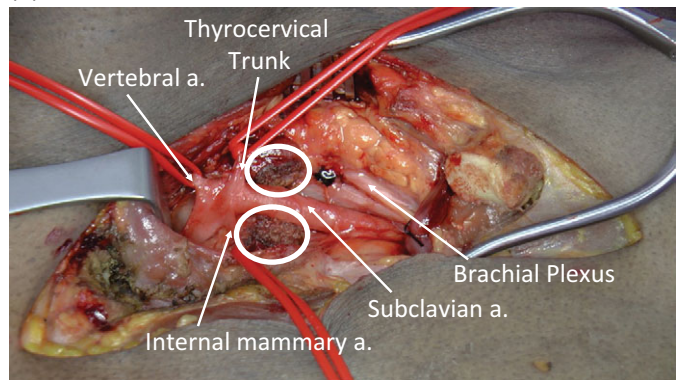


Figure 9.12 (a and b) Exposure of the proximal subclavian artery and its branches after retraction of the divided clavicle, and division of the anterior scalene muscle.

- Identification of the artery may be difficult if there is no pulsation because of proximal injury, thrombosis, or retraction of the transected ends. In these cases, it is easier to expose the axillary artery first (see axillary vessels chapter) and proceed proximally.

Exposure through a Combined Clavicular Incision and Median Sternotomy

- After the clavicular exposure, a standard median sternotomy is performed to obtain proximal control of either a left or right subclavian artery injury.

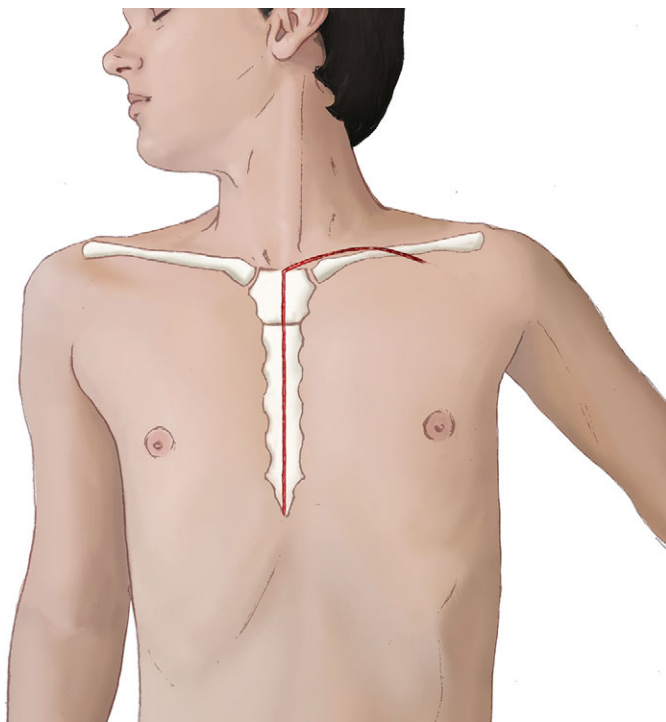


Figure 9.13 Combined clavicular and sternotomy incisions for exposure of the proximal subclavian artery.

- For very proximal control, the artery can be dissected at its origin from the brachiocephalic artery on the right or the aortic arch on the left side. This can be done by dissecting and lifting the thymic remnant and surrounding fat in the upper mediastinum. This exposes the left innominate vein and the aortic arch with its branches. The origin of the subclavian artery (innominate artery on the right and aortic arch on the left side) is then identified and isolated. This approach is described in detail in [Chapter 16](#) (Mediastinal Vessels).

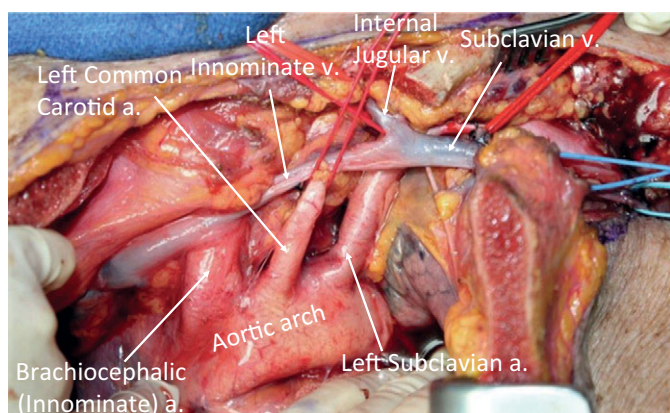
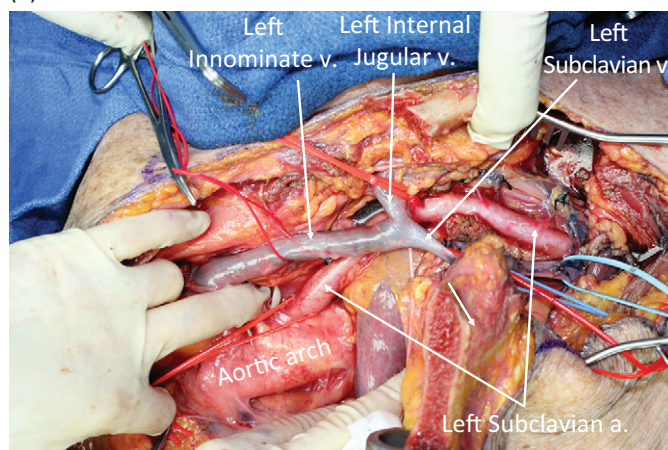


Figure 9.14 Exposure of the aortic arch and its major branches, through a combined clavicular and sternotomy incisions. The left innominate vein crosses transversely over the aortic arch branches and should be retracted superiorly for better exposure.

(a)



(b)

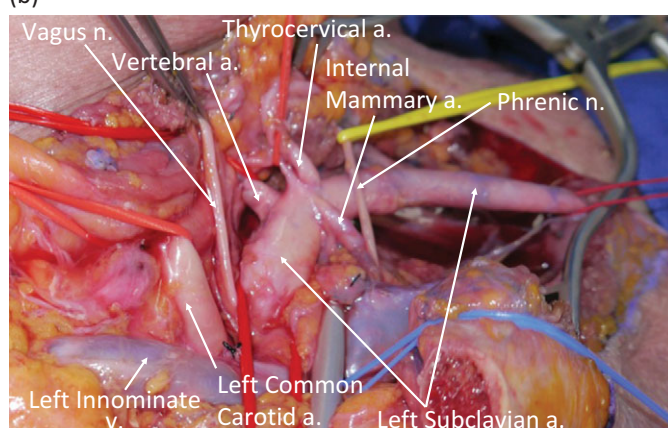


Figure 9.15 (a) Complete exposure of the left subclavian artery through combined clavicular and sternotomy incisions. IJV, internal jugular vein.

(b) Complete exposure of the left subclavian artery and its major branches. Note the phrenic nerve, which is lateral to the internal mammary artery (IMA), and the vagus nerve, which is medial to the artery.

Exposure through a Supraclavicular Incision

- This incision is rarely used in trauma, because of the limited exposure and poor proximal and distal control it provides. It may be considered in stable patients with distal subclavian arterial injuries.
- A transverse skin incision is made approximately two fingerbreadths above the medial half of the clavicle, extending between the medial border of the sternal head of the sternocleidomastoid muscle, approximately. Carry the incision through the platysma and identify the clavicular head of the SCM muscle.

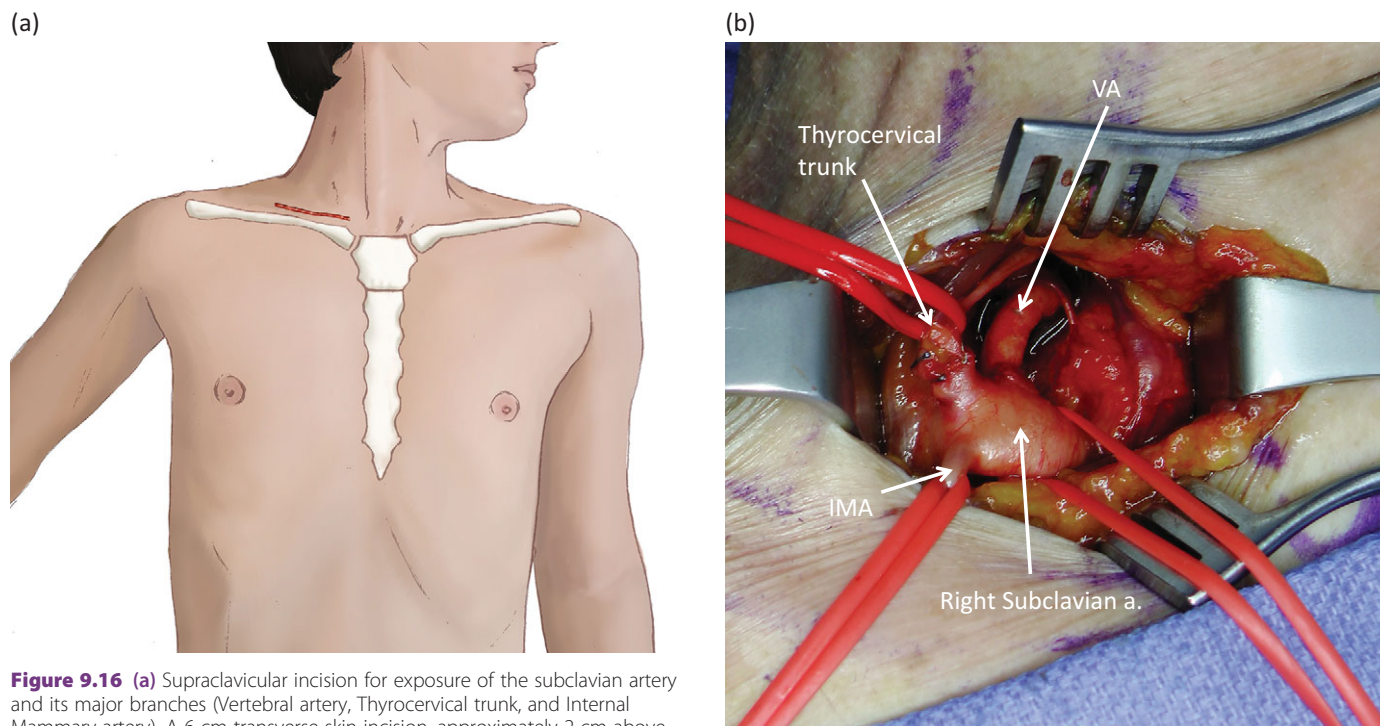


Figure 9.16 (a) Supraclavicular incision for exposure of the subclavian artery and its major branches (Vertebral artery, Thyrocervical trunk, and Internal Mammary artery). A 6-cm transverse skin incision, approximately 2 cm above the medial half of the clavicle.

The platysma is then divided. The clavicular head of the sternocleidomastoid muscle is divided approximately 1 cm from its clavicular insertion.

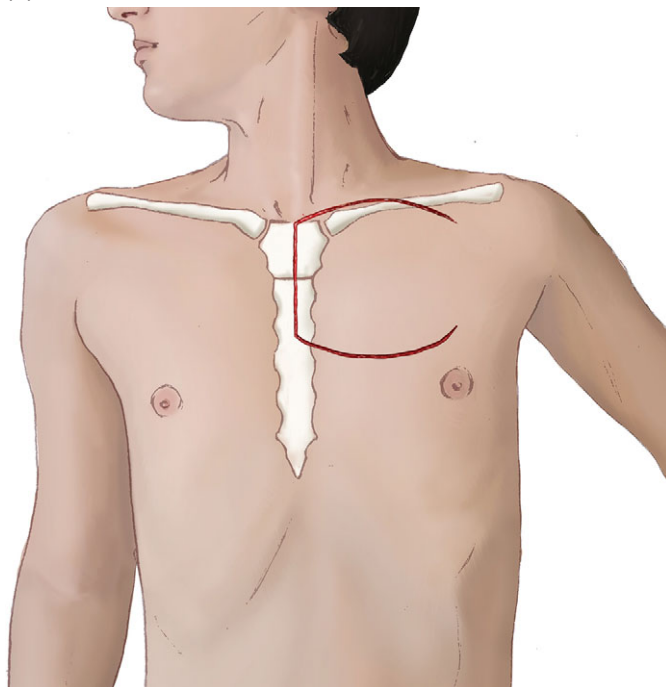
- The subcutaneous tissue above the clavicle is dissected to expose and identify the subclavian vein, which courses more superficial and inferior relative to the artery.
- The anterior scalene muscle is then divided 1 cm above its insertion onto the first rib. The vein is located in front and the artery is behind the muscle. Identify and preserve the phrenic nerve located on the anterior surface of the muscle. The subclavian artery is then identified and isolated (Figure 9.16b).

Figure 9.16 (b) Dissection through the fat pad between the sternal and clavicular heads of the SCM exposes the anterior scalene muscle. Division of the anterior scalene muscle allows exposure of the subclavian artery and three of its branches: the vertebral artery (VA), the thyrocervical trunk, and the internal mammary artery (IMA).

Exposure through a “Trap-Door” Incision

This incision may be used to expose the proximal left subclavian artery. The “trap-door” approach combines a supraclavicular incision, a midline sternotomy through the manubrium and upper portion of the sternum, and an anterior left thoracotomy through the third or fourth intercostal space.

(a)



(b)

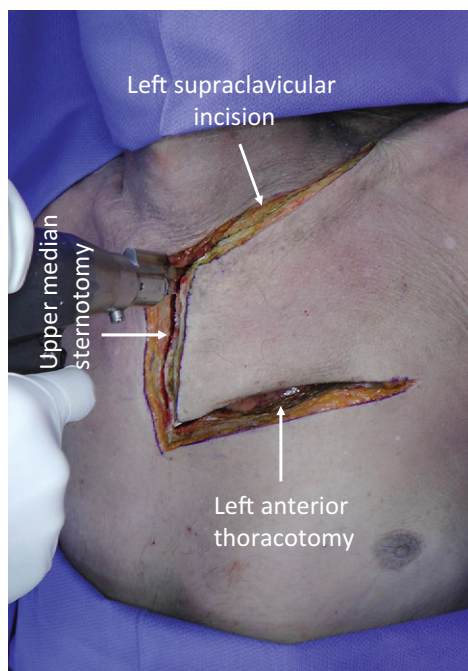


Figure 9.17 (a) Trap-door incision combines a clavicular incision, upper median sternotomy, and a third or fourth intercostal space left thoracotomy. (b) The “trap-door exposure”: The manubrium and upper portion of the sternum are divided in the midline, using a sternal saw. A second incision is performed along the upper border of the clavicle, detaching the clavicular and sternal heads of the SCM muscle. A third incision is performed through the third or fourth intercostal space and extends to the anterior axillary line.

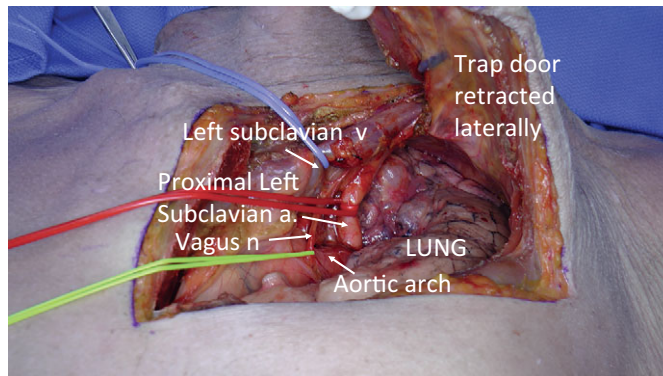


Figure 9.18 The left subclavian vein is isolated and retracted (blue vessel loop), exposing the proximal left subclavian artery (red vessel loop) at its origin from the aortic arch. The left vagus nerve (yellow vessel loop) is identified and protected.

The “trap door” is then retracted laterally and the proximal subclavian vessels are identified and dissected. The vein is more superior and superficial to the artery and needs to be dissected free and retracted in order to allow exposure of left subclavian artery as it arises from the aortic arch. The vagus nerve lies between the artery and the vein, medial to the internal mammary artery.

This exposure is, however, associated with greater morbidity, including bleeding, iatrogenic rib fractures, severe post-operative pain, and more common respiratory complications, when compared to the above described clavicular/median sternotomy approach.

Vascular Reconstruction

- Primary arterial repair is rarely possible. In the majority of cases, reconstruction using a synthetic or an autologous saphenous vein graft is necessary. The choice of graft (autologous or synthetic) is a matter of personal preference, the general condition of the patient, and the availability of an appropriately sized saphenous vein. Standard vascular techniques are used.
- The subclavian artery should never be ligated, even in hemodynamically unstable patients, because of the significant risk of limb ischemia. For patients requiring damage control, a temporary shunt with subsequent semielective, definitive reconstruction is recommended.
- The subclavian vein can be ligated without any significant complications. Repair should be considered only if it can be done with simple techniques and without producing significant stenosis. Stenosis greater than 50% increases the risk of thrombosis and pulmonary embolism.
- At the completion of the operation, assess for a palpable peripheral pulse and for any evidence of compartment syndrome. On-table angiography should be considered in cases with only a Doppler signal. Routine prophylactic fasciotomies are not necessary; however, therapeutic fasciotomies should be performed without delay.

Wound Closure

- The continuity of the divided clavicle can be reestablished with wiring or plating. In cases of disarticulation, the periosteum and ligaments around the sternoclavicular joint are repaired.
- The continuity of the sternum is established with wiring.
- The platysma should be reapproximated separately for good cosmetic results. Failure to do so can result in retraction of the muscle and poor aesthetics.

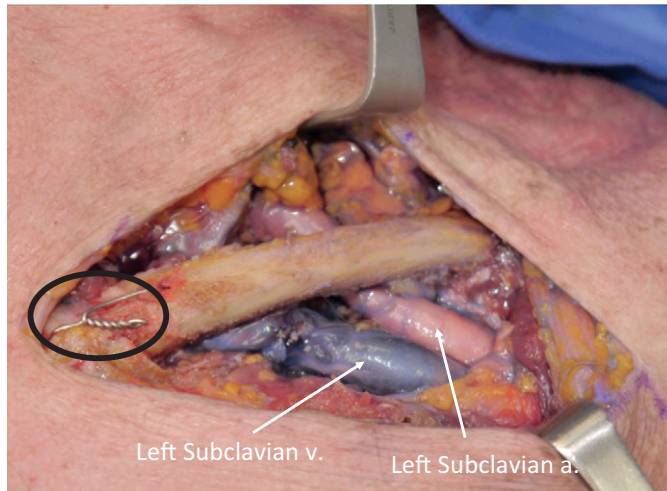


Figure 9.19 The divided left clavicle is reconstructed with wiring (black circle).

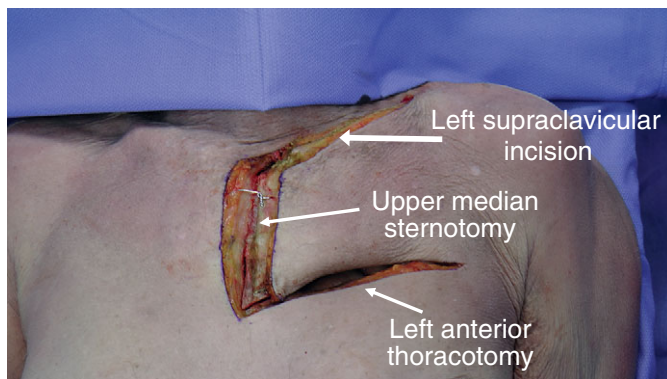


Figure 9.20 The sternotomy part of the trap door is closed with wires and the other two incisions with the standard closure in layers.

Tips and Pitfalls

The subclavian artery lies deep behind the clavicle, and its exposure can be challenging. Its proximal segment is approximately 5–6 cm from the skin and extensive dissection of the surrounding pre-scalene muscle fat is required.

- Intraoperative use of ultrasound may be helpful to identify the artery.
- In the absence of pulsation (thrombosis or complete transection), start with the much easier exposure of the axillary artery and proceed proximally towards the injury.
- For very proximal injuries, start with the isolation of the origin of the subclavian artery, through the combined clavicular incision/median sternotomy, and proceed distally.

Postoperatively, monitor for peripheral pulses and for the development of compartment syndrome.

- There is no role for routine prophylactic fasciotomy.
- Administration of mannitol intraoperatively and postoperatively in hemodynamically stable patients may reduce the risk of developing compartment syndrome.

The phrenic nerve is at risk of transection during the division of the anterior scalene muscle for proximal injuries. This will result in paralysis of the ipsilateral diaphragm. Identify and protect it prior to the division of the muscle.

During dissection of the right subclavian artery, isolate and preserve the Recurrent Laryngeal Nerve, which loops around the proximal subclavian artery anteriorly prior to ascending (posteriorly) into the neck.

During dissection of the subclavian vein near its junction with the internal jugular vein, protect the thoracic duct, which drains into this part of the vein. If injured, ligate both ends. Failure to recognize and ligate the injured duct results in a troublesome postoperative chyle leak.

Axillary Vessels

Demetrios Demetriades and Emilie Joos

Surgical Anatomy

- External landmarks: The axillary vessels start at the middle of the clavicle, course deep under the deltopectoral groove, and end at the lateral border of the axilla.
- The axillary artery is divided by the pectoralis minor into three parts: the first part is proximal to the muscle and gives one branch. The second part is under the muscle, is surrounded by the cords of the brachial plexus, and gives two branches. The third part lies lateral to the muscle, is surrounded by the nerves of the brachial plexus, and gives three branches.
- The axillary vein is the continuation of the basilic vein. Prior to its transition to the subclavian vein, the cephalic vein joins it. Its middle segment lies under the pectoralis minor muscle, inferior to the axillary artery.

General Principles

- Ligation of the axillary artery is associated with a high incidence of limb loss and should not be performed. In critically unstable patients, temporary shunting with delayed reconstruction should be considered.
- Vascular reconstruction can be done with either a saphenous vein graft or a synthetic graft.

Special Surgical Instruments

- A standard vascular tray.
- Periosteal elevators and Doyen Raspatory may be needed for clavicular resection and exposure of the distal subclavian vessels. See [Chapter 9 Subclavian Vessels](#).

Positioning

- The patient should be in the supine position, with the injured arm abducted from the body at about 30°. The head is slightly turned to the opposite side.

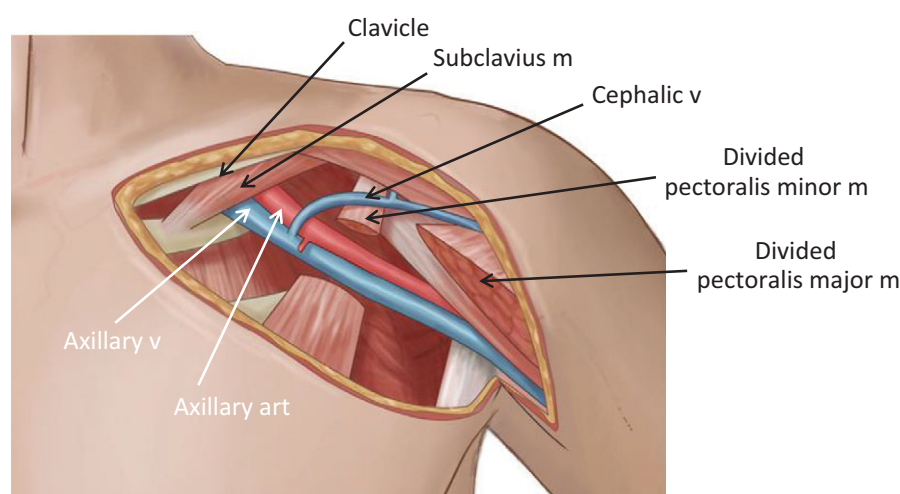


Figure 10.1 The axillary vessels start under the middle of the clavicle and curve downward, deep under the deltopectoral groove. Part of the vessels is under the pectoralis minor muscle. The vein is below and more superficial to the artery. Note the cephalic vein crossing over the pectoralis minor muscle and draining into the proximal axillary vein.

- The neck, arm, and entire chest should be fully prepped. The groin should be included in the surgical field in case a vein harvest is needed.

Incision

- The incision starts just below the middle of the clavicle, and courses over the deltopectoral groove.
- In very proximal injuries the incision should start at the sternoclavicular junction, course directly over the medial half of the clavicle and, at the middle of the clavicle, curve downward into the deltopectoral groove. The clavicle may have to be divided to allow proximal vascular control (see Chapter 9 subclavian vessels).

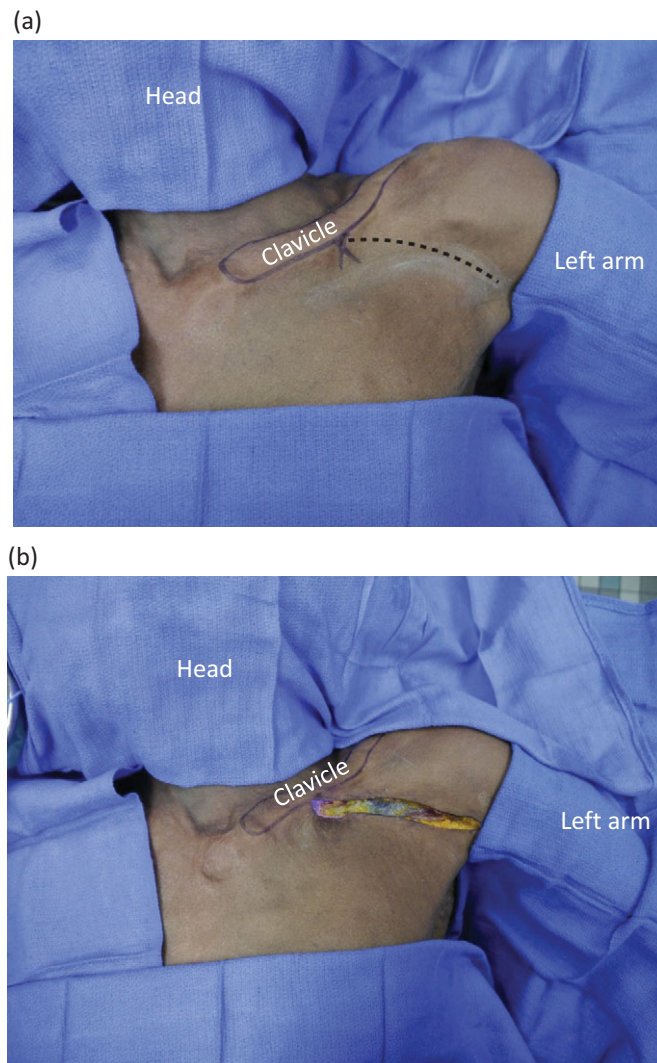


Figure 10.2 (a, b) The standard incision for the exposure of the axillary vessels starts just below the middle of the clavicle, and courses over the deltopectoral groove. The cephalic vein courses superficially in the groove and should be avoided.

Vascular Exposure

- The subcutaneous tissue under the incision is dissected into the deltopectoral groove. The cephalic vein will come into view and can be retracted or ligated.
- The lower skin flap is mobilized to allow good exposure of the pectoralis major and its insertion into the humerus.
- The pectoralis major muscle fibers are split and retracted, exposing the underlying pectoralis minor muscle. However, in severe active bleeding or if the exposure is not satisfactory, the pectoralis major is divided about 2–3 cm from its insertion into the humerus and retracted medially. The underlying pectoralis minor muscle comes into full view.

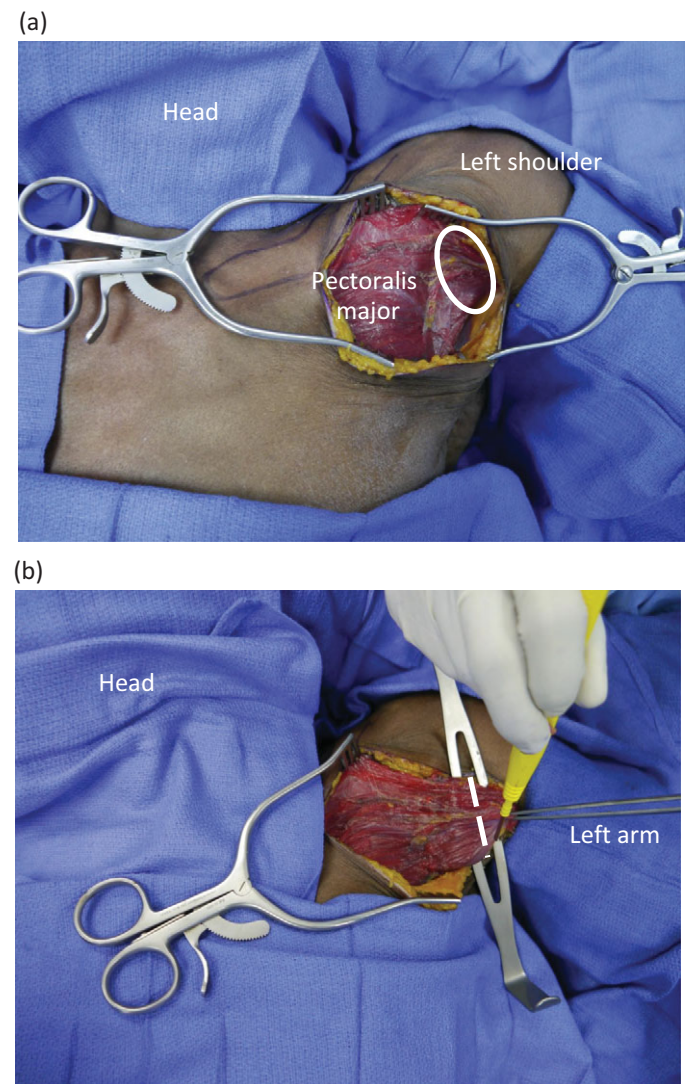
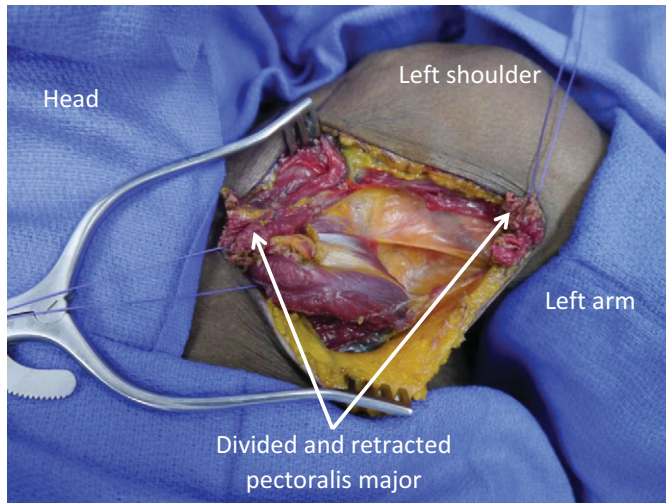


Figure 10.3 (a, b) The lower skin flap is mobilized to allow good exposure of the pectoralis major and its insertion into the humerus (circle). The muscle might be split to expose the underlying pectoralis minor. However, for faster and better exposure, its insertion into the humerus may be divided 2–3 cm from the bone.

- The pectoralis minor is then retracted laterally or divided near its insertion into the coracoid process and retracted medially.

(a)



- The vein will first come into view, inferior and anterior to the artery.
- The axillary vessels are now fully exposed, with the brachial plexus roots and nerves surrounding them.

(b)

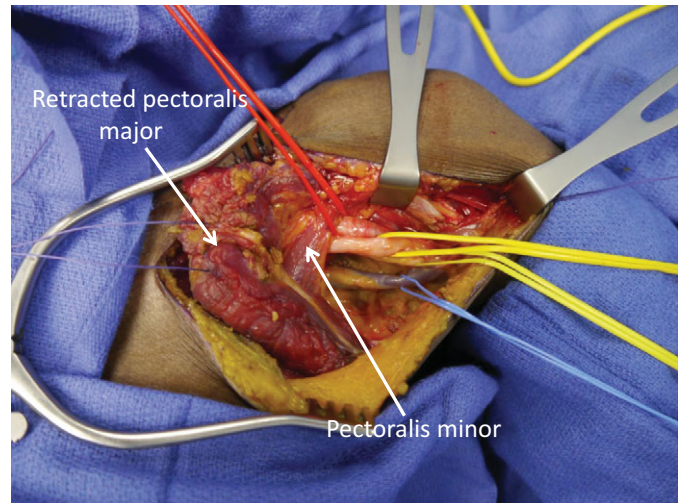
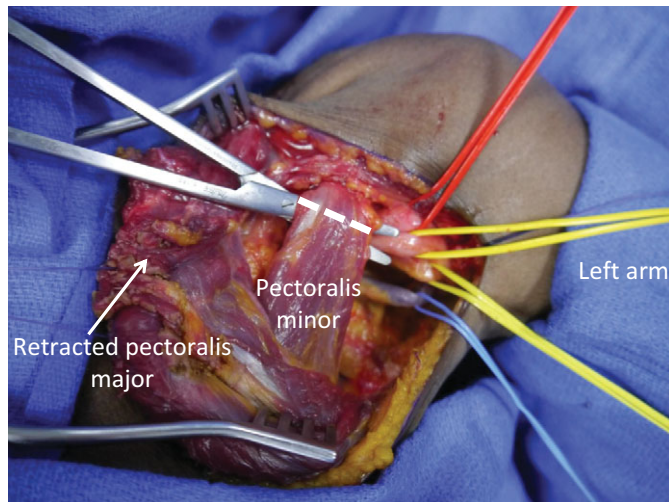


Figure 10.4 (a) Heavy absorbable sutures are placed on the divided edges of the pectoralis major. The edges are retracted to expose the underlying pectoralis minor muscle. At the completion of the operation, the sutures are tied together to reconstruct the muscle. (b) Retraction of the divided pectoralis major exposes the underlying pectoralis minor and the distal subclavian vessels and brachial plexus. Note the roots of the brachial plexus (artery in red vessel loop, vein in blue, and nerves in yellow). The middle part of the axillary vessels is underneath the pectoralis minor muscle.

(a)



(b)

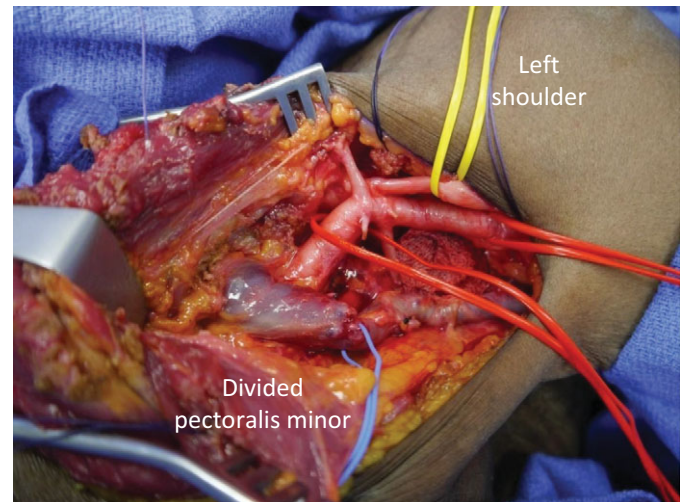


Figure 10.5 (a) Division of the pectoralis minor exposes the middle part of the subclavian vessels. (b) After division of the pectoralis minor muscle, the axillary vessels are completely exposed (artery in red vessel loop, vein in blue, and nerves in yellow).

Vascular Injury Management

- The axillary artery should always be repaired or reconstructed. Damage control with temporary shunting and delayed reconstruction should be considered in patients in extremis.
- The arterial reconstruction can be done with either a synthetic or an autologous saphenous vein graft.
- The axillary vein should be repaired only if it can be done with simple suturing. Complex graft reconstruction is not advisable. Ligation of the vein is well tolerated.
- The divided pectoralis major muscle should be reapproximated, using absorbable sutures.

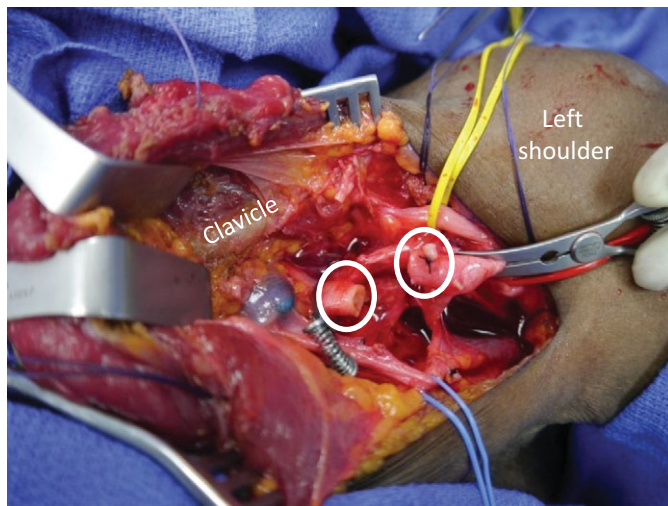


Figure 10.6 The injured part of the axillary artery is debrided to healthy tissues (circles). Reconstruction usually requires a synthetic size 6 or 8 graft (vein in blue vessel loop and nerves in yellow).

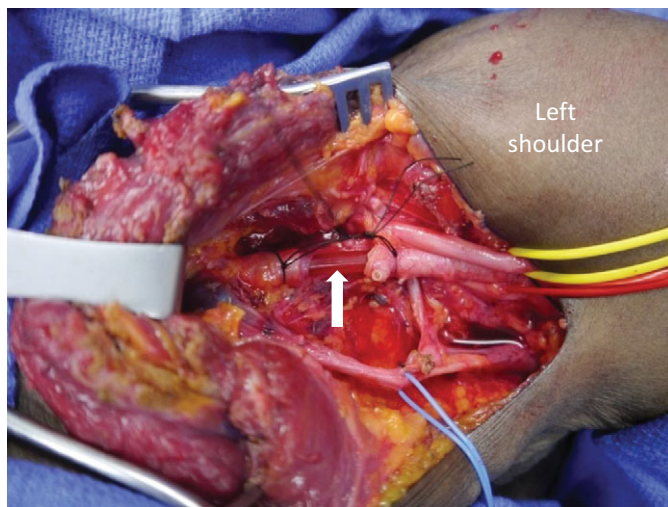


Figure 10.7 Damage control with temporary shunt (arrow). The sutures securing the tube proximally and distally are tied together to prevent accidental dislodgement. (vein in blue loop and nerves in yellow).

Closure

- Reconstruction of the pectoralis minor is likewise performed.

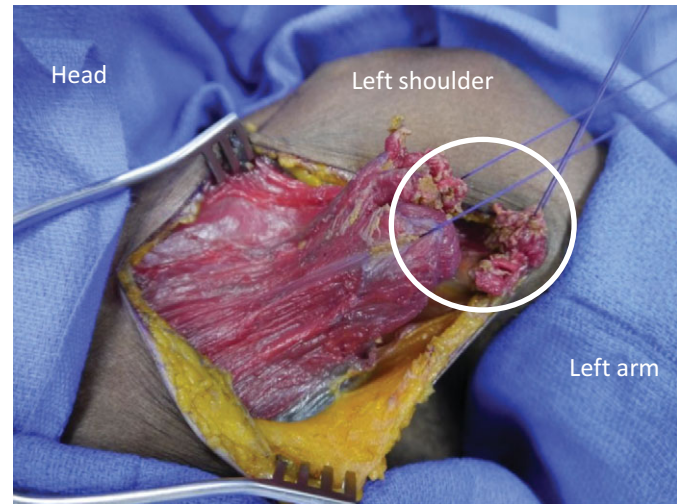


Figure 10.8 Reconstruction of the pectoralis major muscle.

Tips and Pitfalls

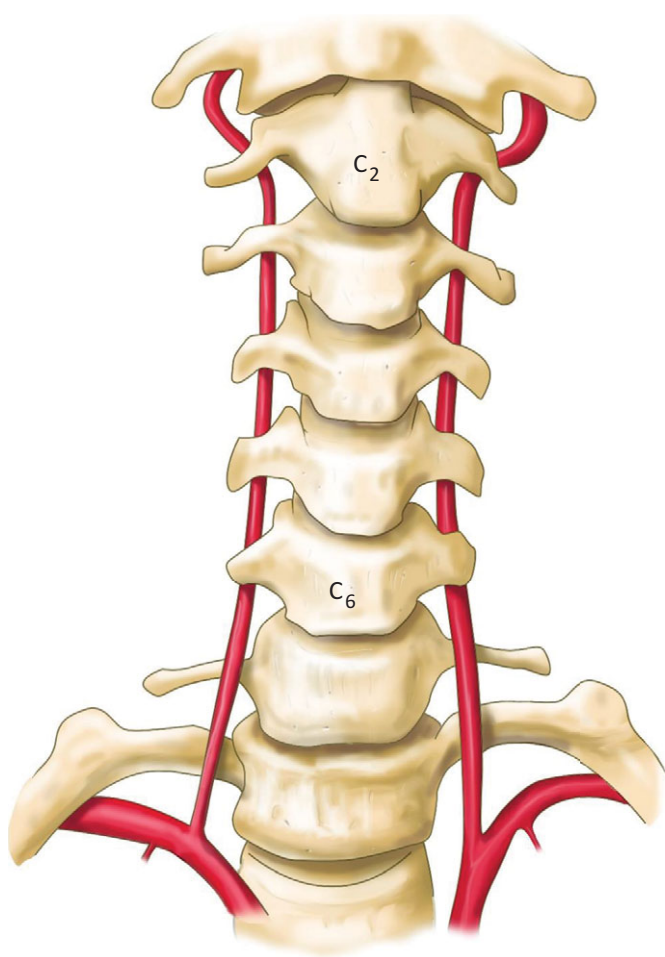
- **Positioning:** Excessive abduction of the arm distorts the anatomy and makes the exposure more difficult.
- To obtain proximal control of the subclavian artery, resection of the proximal clavicle may be required.
- If there is ongoing bleeding and rapid exposure is needed, the pectoralis major and minor muscles should be divided, as described above.
- Care must be taken not to injure the brachial plexus, which is intimately associated with the axillary vessels.
- In cases where there was prolonged ischemia due to an arterial injury, monitor closely for compartment syndrome. There is no need for routine prophylactic arm fasciotomy. Intraoperative administration of mannitol in stable patients may reduce the risk of compartment syndrome.

Vertebral Artery Injuries

Demetrios Demetriades, Morgan Schellenberg, and Nick A. Nash

Surgical Anatomy

- The vertebral artery (VA) is the first cephalad branch of the subclavian artery. From a trauma surgery perspective, the VA is divided into three parts. Part I runs from its origin at the subclavian artery to C6, where it enters the transverse foramen. Part II courses in the bony vertebral canal, formed by the transverse foramen of C6 to C1. Part III runs outside the vertebral canal, from C1 to the base of the skull. The VA enters the skull through the foramen magnum, piercing the dura mater. It joins the contralateral VA to form the basilar artery, which is part of the circle of Willis.



- The first part of the VA can be landmarked externally by the triangle formed by the sternal and clavicular heads of the sternocleidomastoid (SCM) muscle and the clavicle. It runs upward and backward between the anterior scalene and longus colli muscles, before entering the vertebral canal at the C6 level.
- The carotid sheath is anterior and medial to the first part of the VA.
- The external landmark of C6, where the VA enters into the vertebral canal and the second part of the VA begins, is the cricoid cartilage.
- The VA is surrounded by a venous plexus.

General Principles

- Most VA injuries can be effectively managed with angioembolization. Angiographic intervention is the preferred therapeutic modality for these injuries due to the difficult anatomy and complexity of the operative exposure. Operative management with direct surgical control of the bleeding is reserved for cases with severe active bleeding or if interventional radiology is not available.
- Ligation or endovascular occlusion of the VA is tolerated well and rarely causes neurological deficits.
- Gunshot wounds to the VA are often associated with spinal fractures and spinal cord injuries.

Special Surgical Instruments

- Equipment for the operation should include a major vascular tray for trauma, periosteal elevator, and bone rongeurs.

Positioning

- The patient should be positioned supine. If the cervical spine has been cleared, the head should be turned away from the injured side with the neck slightly extended. This can be aided by placing a folded towel between the patient's shoulders.

Figure 11.1 Anatomy of the vertebral artery (VA). The VA is the first cephalad branch of the subclavian artery and is divided into three parts. The first part courses from its origin off the subclavian artery to C6, where it enters the transverse foramen. Part II runs in the bony vertebral canal between C6 and C1. The third part travels from C1 to the skull base.

Exposure of Part I of the VA

Incision

- A supraclavicular transverse incision may be used on rare occasions for exposure of the proximal VA, outside the vertebral canal. This is a limited exposure and does not allow satisfactory exploration of the carotid sheath or the aerodigestive tract.
- To accomplish this, begin by marking the sternal and clavicular heads of the SCM muscle. Perform a transverse skin incision, extending between the medial border of the sternal head and the lateral border of the clavicular head of the SCM muscle, approximately two fingerbreadths above the clavicle. Carry this incision through the platysma and identify the sternal and clavicular heads of the SCM muscle.

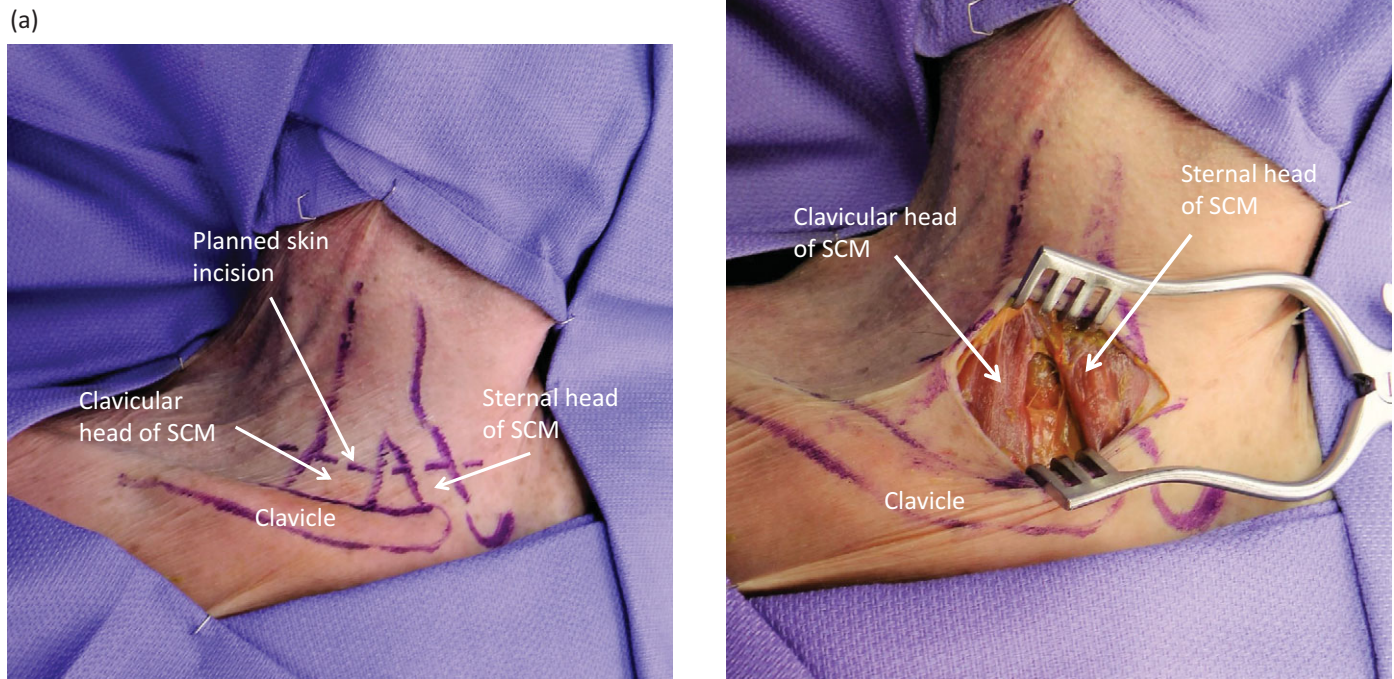
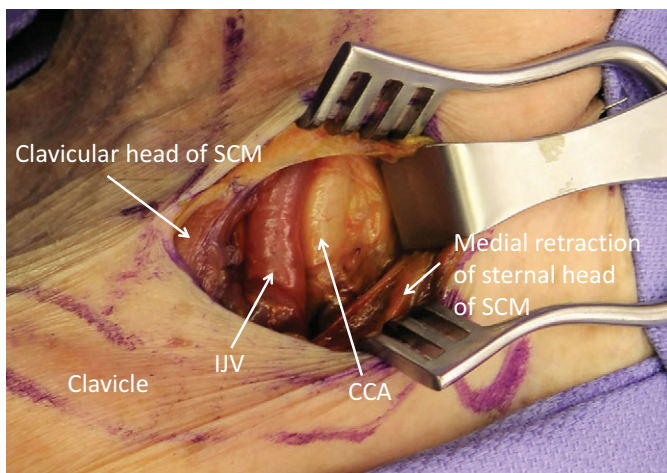


Figure 11.2 Supraclavicular skin incision for exposure of the first part of the right vertebral artery. A transverse skin incision is made about 2 cm above the clavicle, centered over the sternal and clavicular heads of the SCM muscle (a). Following the division of the platysma, the sternal and clavicular heads of the SCM muscle are exposed (b).

Exposure

- Continue the dissection deep into the base of the triangle. Place a self-retaining retractor in the wound, retracting the sternal head of the SCM muscle medially and the clavicular head laterally. If necessary, divide the clavicular head of the SCM muscle near the clavicle or split the muscle heads superiorly.
- The carotid sheath is the first vascular structure to be identified in the medial part of the triangle. The jugular vein is lateral, the common carotid artery medial, and the vagus nerve posterior. The structures of the carotid sheath are dissected and retracted medially to expose the scalene fat pad.

(a)



(b)

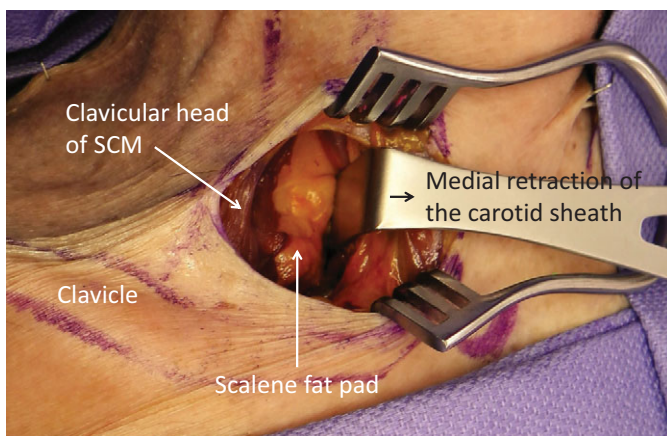
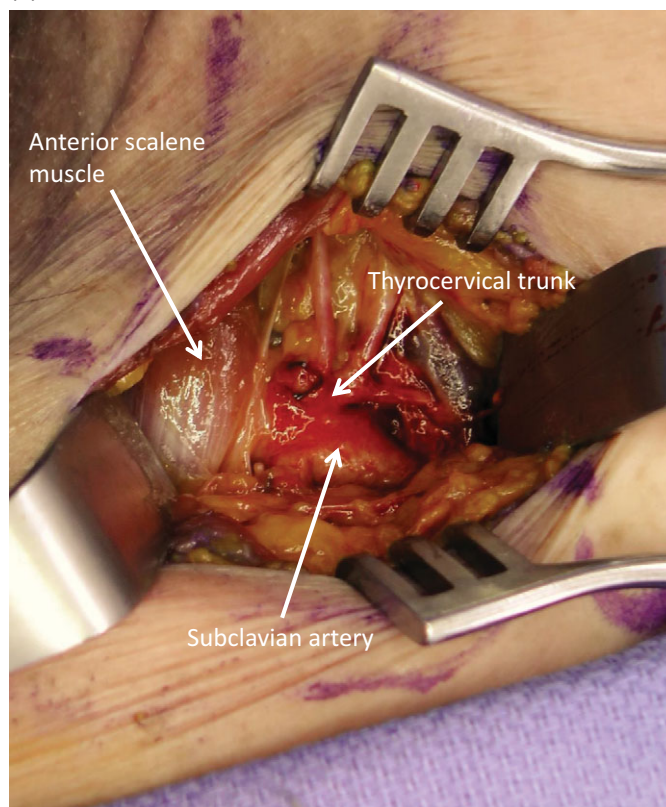


Figure 11.3 Exposure of the carotid sheath and scalene fat pad. (a, b) The sternal head of the SCM muscle is retracted medially and the clavicular head laterally, exposing the internal jugular vein (IJV) and the common carotid artery (CCA) and the scalene fat pad, in the triangle formed by the two heads of the SCM and the clavicle.

- The scalene fat pad is visualized and dissected to expose the anterior scalene muscle. The phrenic nerve will be running on the surface of the anterior scalene muscle and must be protected. The muscle is retracted laterally or divided. This exposes the subclavian artery and two of its branches: the thyrocervical trunk and the internal mammary artery.

(a)



(b)

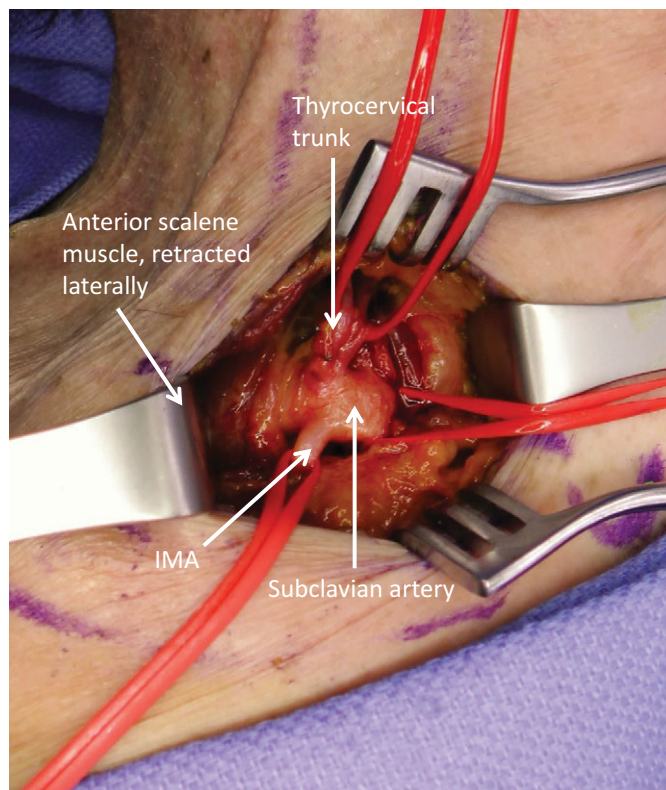


Figure 11.4 Identification of the anterior scalene muscle and subclavian artery. (a, b) Dissection through the fat pad between the sternal and clavicular heads of the SCM exposes the anterior scalene muscle. Retraction or division of the anterior scalene muscle allows exposure of the subclavian artery and three of its branches: the vertebral artery, the thyrocervical trunk, and the internal mammary artery (IMA).

- The first part of the VA is located deeper and more medially, between the anterior scalenus laterally and longus colli muscle medially. Identification of the vessel is greatly facilitated by palpating, with the tip of the index finger, the groove between the vertebral body of C7 and the transverse process. The VA lies immediately anterior to this groove. A right angled clamp is used to dissect the VA. Care should be taken not to injure the vertebral venous plexus, which is located in front of the artery.
- The phrenic nerve is seen laterally, on the surface of the anterior scalenus muscle and should be protected.

Sternocleidomastoid Incision Approach

Incision

- This is the preferred incision in trauma. It allows exploration of the carotid artery, the internal jugular vein, the aerodigestive tract, and Part I and II of the VA.
- The incision is placed over the anterior border of the SCM muscle, extending from just below the mastoid process to the suprasternal notch.

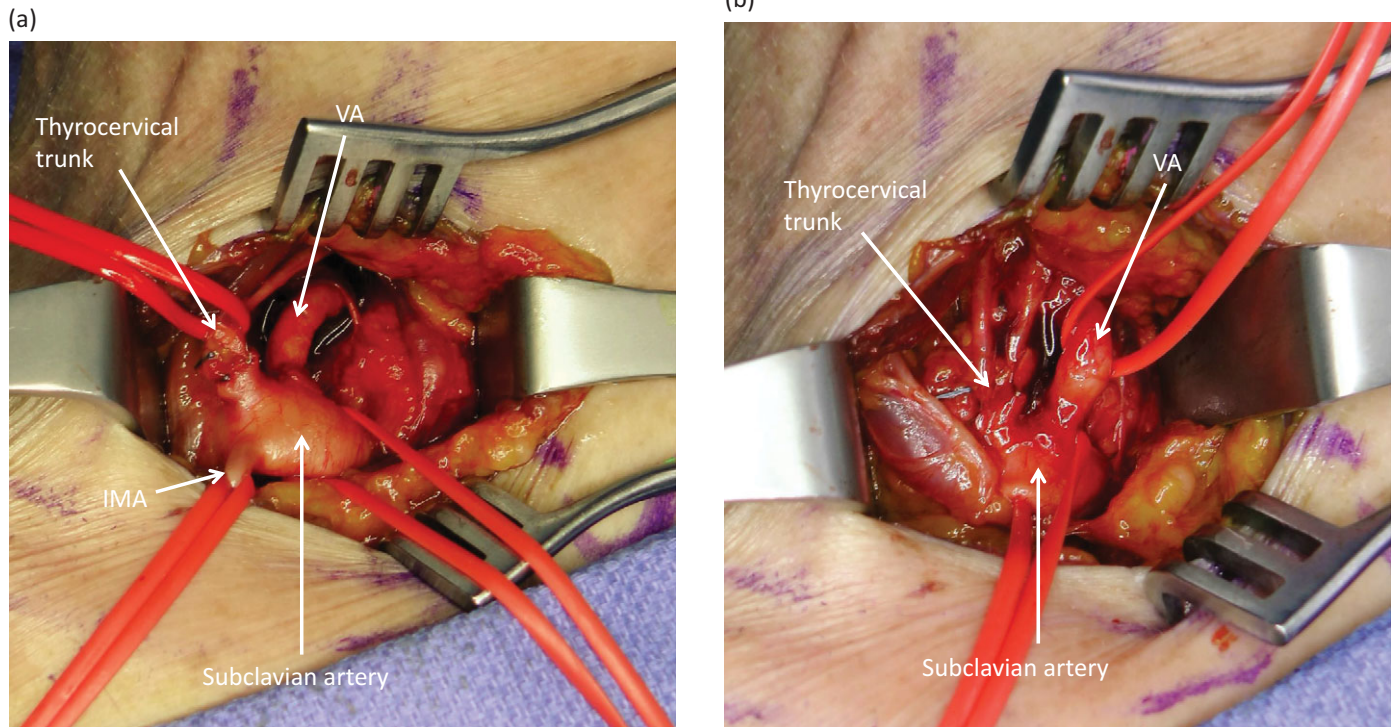
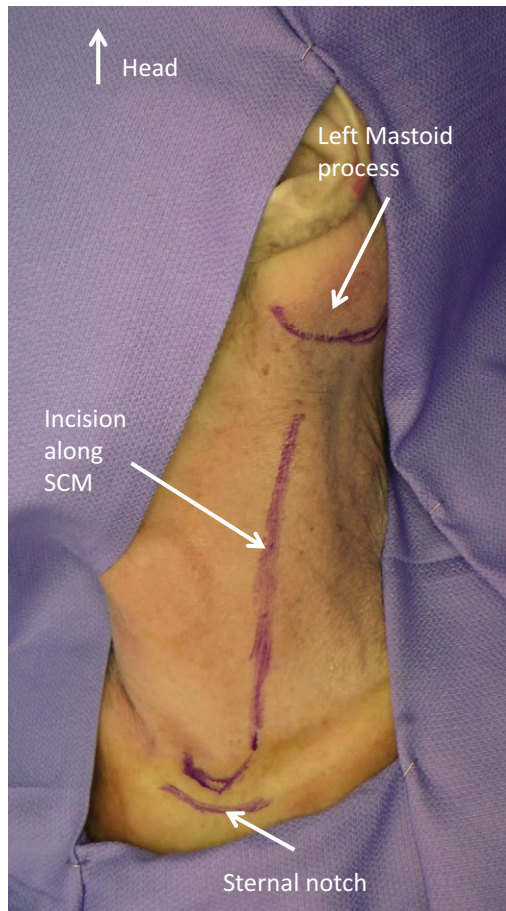
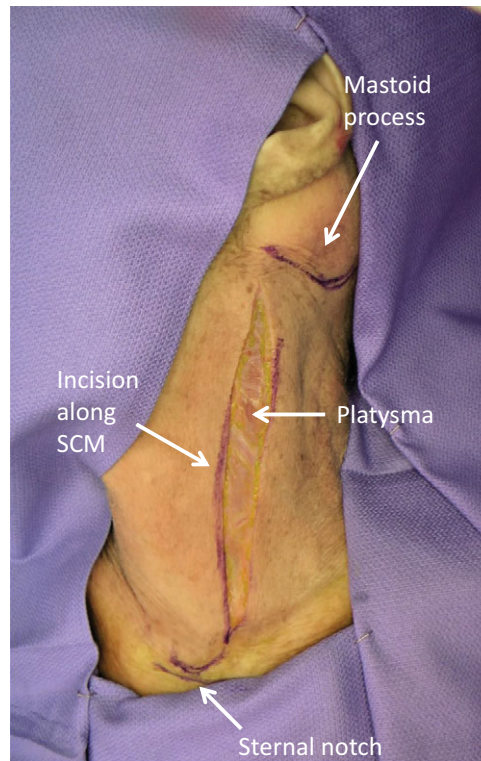


Figure 11.5 Identification of the proximal vertebral artery. (a and b) The vertebral artery is located medial to the thyrocervical trunk.

(a)



(b)



(c)

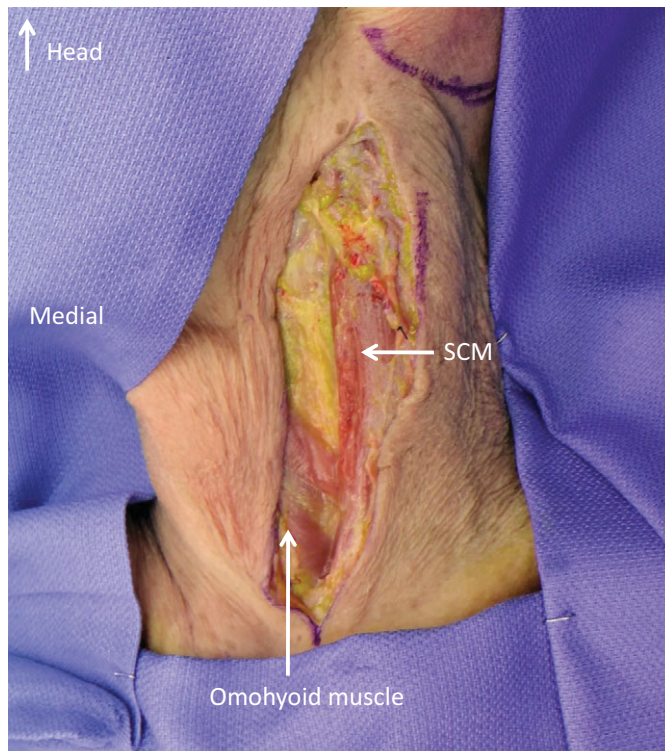


Figure 11.6 Sternocleidomastoid (SCM) muscle incision. The incision is made along the anterior border of the SCM, and extends from below the mastoid process to the suprasternal notch (a). The incision is carried down through platysma and the anterior border of the SCM muscle is exposed. The superior belly of the omohyoid muscle is seen in the lower part of incision.

Exposure

- The dissection is continued through the platysma, until the anterior border of the SCM is encountered. The SCM is retracted laterally to expose the carotid sheath and its contents. The internal jugular vein is more superficial and lateral, the common carotid artery medial, and the vagus nerve is situated posterior and in between these two structures.

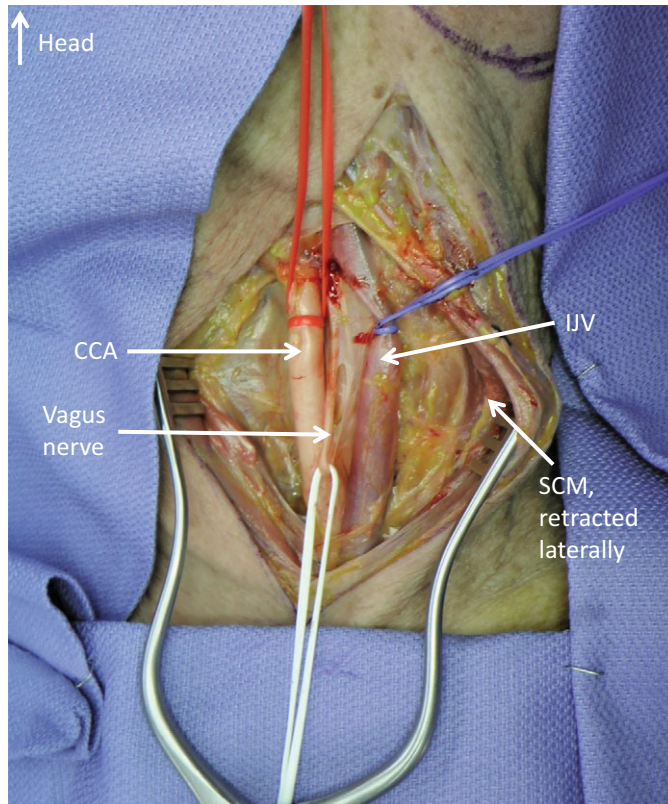


Figure 11.7 Exposure of the left carotid sheath. Lateral retraction of the SCM exposes the carotid sheath and its contents: the IJV, CCA, and vagus nerve.

- The carotid sheath is retracted medially. The midline structures of the neck, which include the esophagus, trachea, and larynx, may also be encountered during this portion of the dissection and should be gently retracted medially.
- The anterior scalene muscle is retracted laterally or divided while protecting the phrenic nerve, which lies on top of the muscle. The longus colli muscle, which is on the anterolateral surface of the vertebra, is visualized medially. The first part of the VA is seen between the anterior scalene and the longus colli muscles.

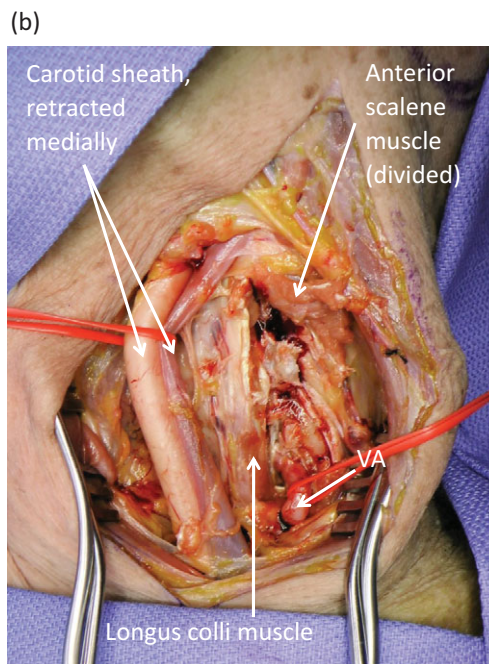
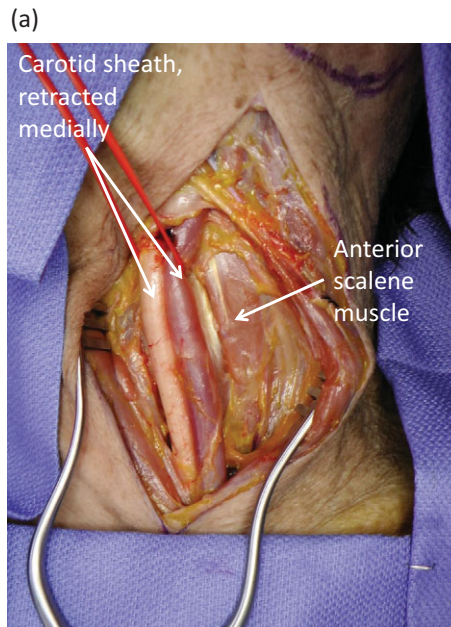


Figure 11.8 Exposure of the left vertebral artery. (a) Medial retraction of the carotid sheath exposes the anterior scalene muscle. (b) Division of the anterior scalene muscle allows exposure of the longus colli muscle. The first part of the VA can now be accessed for proximal control. Access to the second part of the VA is still hindered by the bony vertebral canal.

- The longus colli muscle and prevertebral fascia are swept off the bone of the vertebra with a periosteal elevator, exposing the anterior rim of the vertebral foramen. The rim is located between the vertebral body and the anterior tubercle of the transverse process and is best identified by palpation with the tip of the index finger. This rim is excised with bone rongeurs.

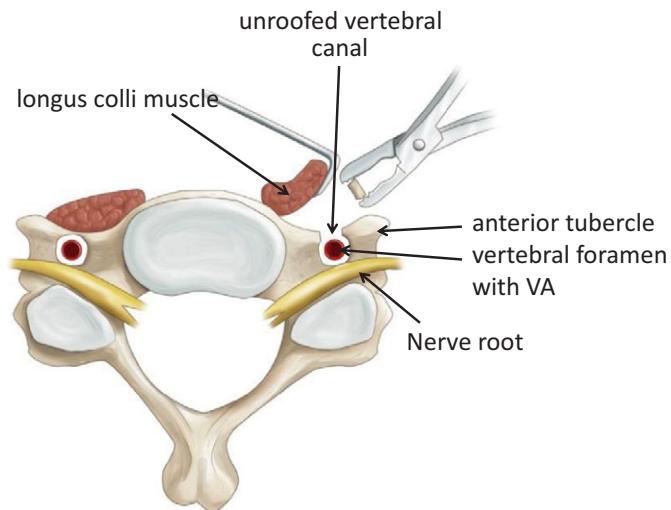


Figure 11.9 Exposure of the second part of the VA. The longus colli muscle is detached and retracted. With the help of bone rongeurs, the vertebral canal is unroofed by excising the anterior rim to expose the VA. The rim can easily be palpated with the tip of the finger, and is located between the body of the vertebra and the anterior tubercle of the transverse process.

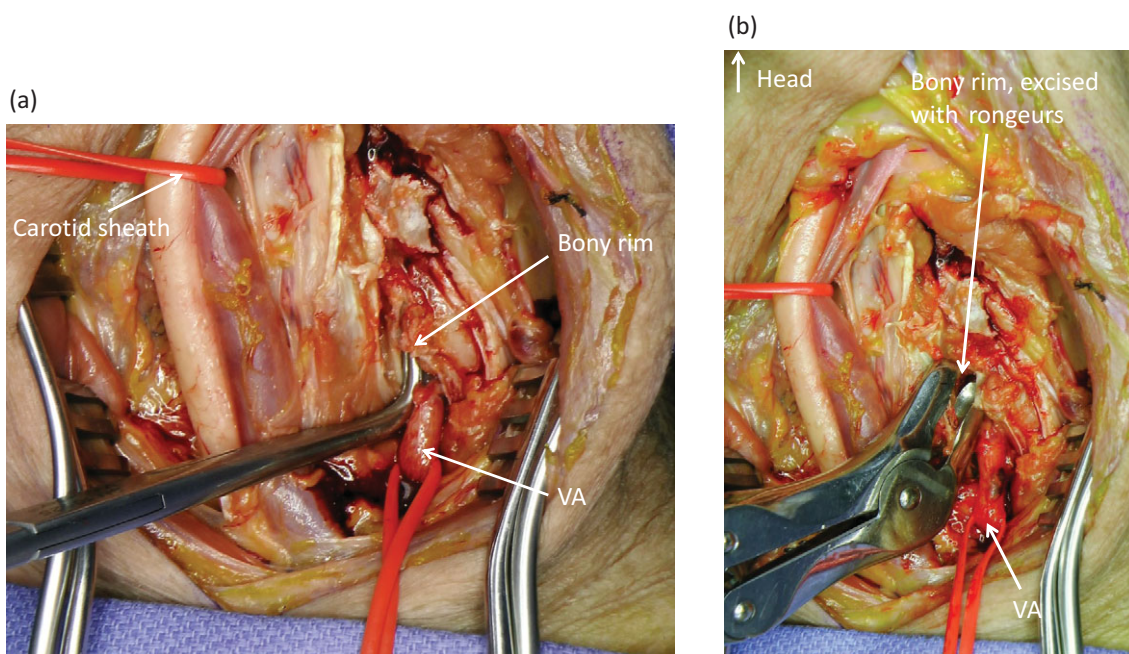


Figure 11.10 Exposure of the second part of the vertebral artery. (a) The right angle dissector demonstrates the entrance of the VA into the vertebral canal, marking the transition from the first to the second part of the VA. (b) Rongeurs are used to excise the bony rim between the vertebral body and anterior tubercle of the transverse process. This can be performed along multiple vertebral levels to allow exposure of the entire second part of the VA.

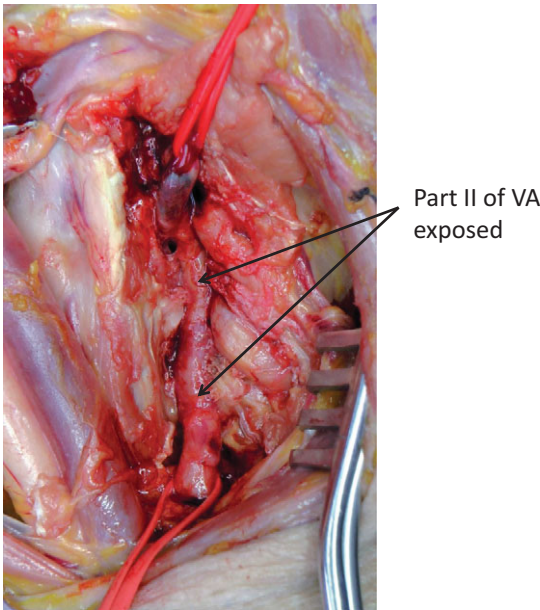


Figure 11.11 Exposure of the second part of the vertebral artery after excision of the anterior rim of multiple transverse processes.

- If necessary, the same process is repeated at the adjacent vertebra for further exposure. Once the injury to the second part of the VA is identified, it can be ligated or repaired depending on the physiologic status of the patient and the extent of the injury.

- The anterior nerve root is posterior to the VA and not at risk of injury if the unroofing is done properly. Troublesome bleeding from the surrounding venous plexus can be controlled with local hemostatic agents and compression.

Tips and Pitfalls

- In hemodynamically stable patients, angioembolization is the preferred management strategy of the injured VA.
- The anatomy of the VA is difficult and the surgeon should consult a surgical atlas when operative intervention is required.
- Proximal ligation of the VA does not effectively control bleeding from a distal injury because of retrograde blood flow.
- For VA injuries above C2, the exposure is extremely difficult and a suboccipital craniectomy by a neurosurgical team may be necessary.
- For penetrating injuries that require emergent exploration due to bleeding, direct visualization and ligation of the VA are often not possible. In these cases, damage control packing of the area with local hemostatic agents followed by postoperative angioembolization is a viable option.

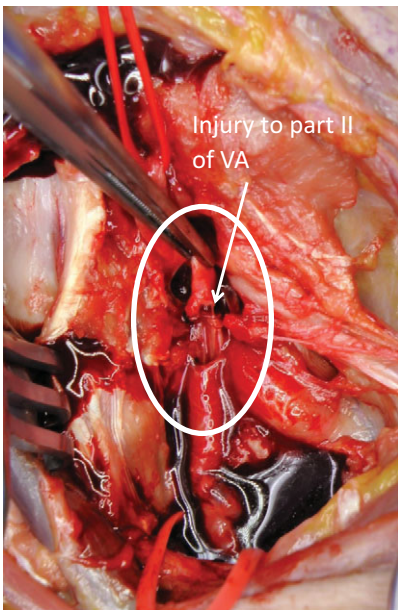


Figure 11.12 Exposure of a penetrating injury to the vertebral artery in the canal, after unroofing the canal. The artery can be ligated or repaired depending on the physiologic status of the patient and the extent of the injury.

Trachea and Larynx

Elizabeth R. Benjamin and Kenji Inaba

Surgical Anatomy

- The trachea is 10–12 cm long and 2–2.5 cm wide, extending from C6 to T5.
- The trachea is composed of 16–20 incomplete rings with a flattened posterior wall of muscle and fibrous tissue.

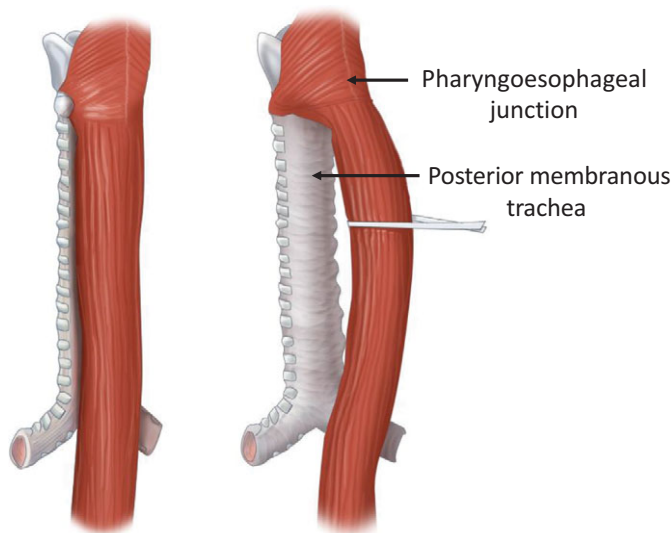


Figure 12.1 The trachea is composed of 16–20 incomplete rings. The posterior membranous portion of the trachea lies just anterior to the esophagus.

- The anatomic borders of the trachea include the isthmus of the thyroid and paired strap muscles anteriorly. The common carotid arteries, thyroid lobes, and recurrent laryngeal nerves form the lateral borders.
- The paired strap muscles are in front of the trachea and larynx. These include the sternohyoid muscles and the underlying sternothyroid and thyrohyoid muscles.
- The thyroid cartilage is suspended from the hyoid bone by the thyrohyoid membrane. The cricothyroid ligament

connects the inferior portion of the thyroid cartilage to the cricoid cartilage. Inferior to this is the first tracheal ring.

- The larynx is composed of three paired (arytenoid, corniculate, and cuneiform), and three unpaired (cricoid, thyroid, and epiglottic) cartilages.

General Principles

- Stridor, respiratory distress, blowing neck wound, hemoptysis, and subcutaneous emphysema are all signs and symptoms of a tracheolaryngeal injury.
- Direct laryngoscopy is used to evaluate for suspected laryngeal injury; bronchoscopy is used to identify tracheal injury.
- In the presence of tracheal trauma, there is a high incidence of associated injury, including vascular and digestive tract injury.
- In suspected airway injury, obtaining a definitive airway should be of highest priority. This is often best achieved in the operating room.

Instruments

- A standard instrument tray can be used for tracheal and laryngeal dissection. Weitlaner or cerebellar retractors and a tracheal hook are recommended for exposure, especially in the deep neck.
- A size 6 and 8 tracheostomy tube should be available in the event of a large tracheal injury or lost airway.

Patient Positioning

- In a patient with isolated neck and no cervical spine injury, it is ideal to place a bump or shoulder roll underneath the upper back and allow the patient's head to extend, thus opening up the neck for improved exposure. This position elevates the trachea and allows for more distal access, above the sternal notch.

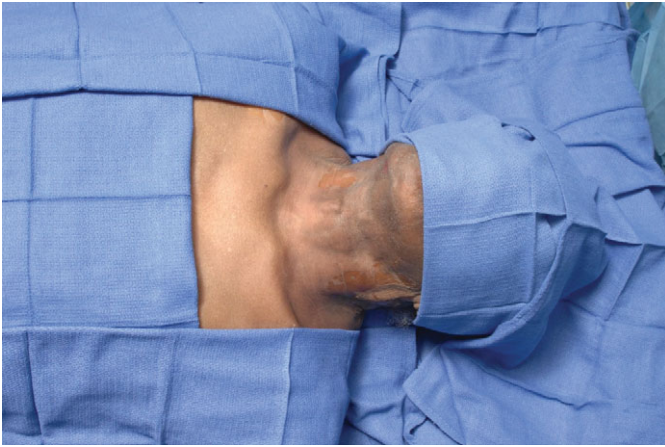


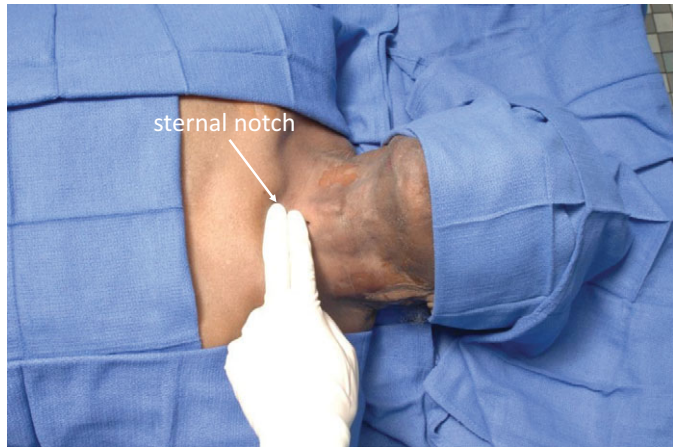
Figure 12.2 A bump is placed between the patient's shoulder blades to allow hyperextension of the neck and improved exposure. Care must be taken to support the head posteriorly on a foam pillow or donut to prevent floating of the occiput and neck strain.

- If there is concern for cervical spine injury, the patient must be kept in spinal precautions and no shoulder roll should be used. Cervical spine stabilization can be accomplished using bilateral sandbags.

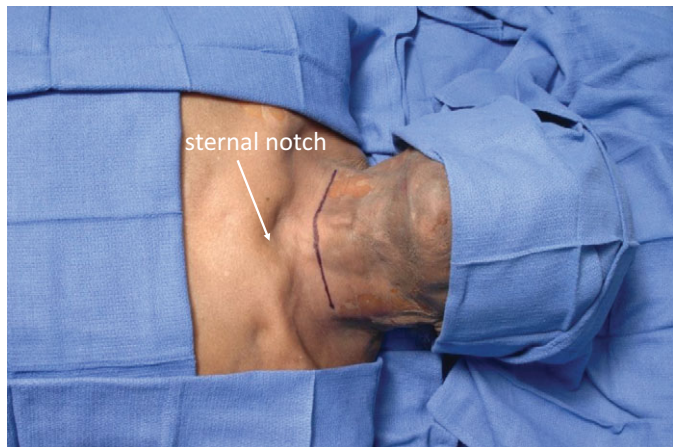
Incisions

- The choice of incision depends on the mechanism of injury (blunt or penetrating), the location of the injury, and the suspected presence of associated injuries (i.e. esophagus or major vessel).
- **Collar Incision**
 - For tracheal injuries, a collar incision is made approximately 2 fingerbreadths above the sternal notch, extending to the medial borders of the sternocleidomastoid muscles.

(a)



(b)



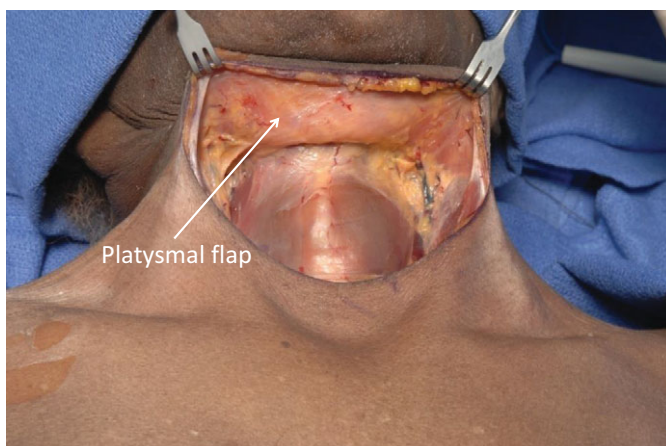
(c)



Figure 12.3 A curvilinear incision is made 2 fingerbreadths above the sternal notch and extending laterally to the sternocleidomastoid muscles (a, b). This incision is carried through the platysma (c).

- After the collar skin incision is made, the platysma is divided, and subplatysmal flaps are created superiorly and inferiorly to expose the strap muscles.

(a)



(b)

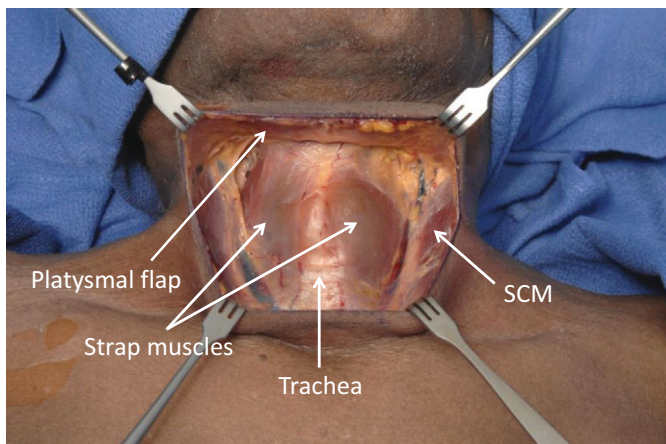
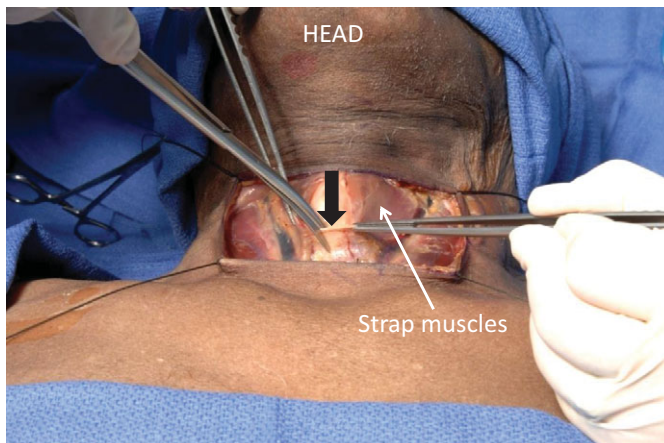


Figure 12.4 (a, b) Subplatysmal flaps are dissected superiorly and inferiorly to expose the underlying strap muscles.

- The strap muscles are divided in the avascular plane along the midline to expose the trachea, larynx, and thyroid gland.

(a)



(b)

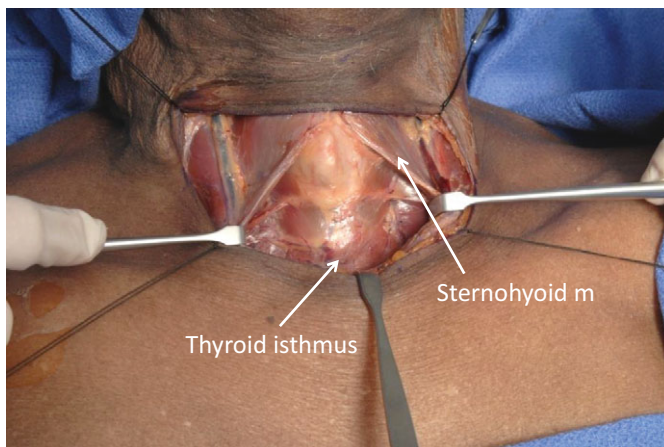
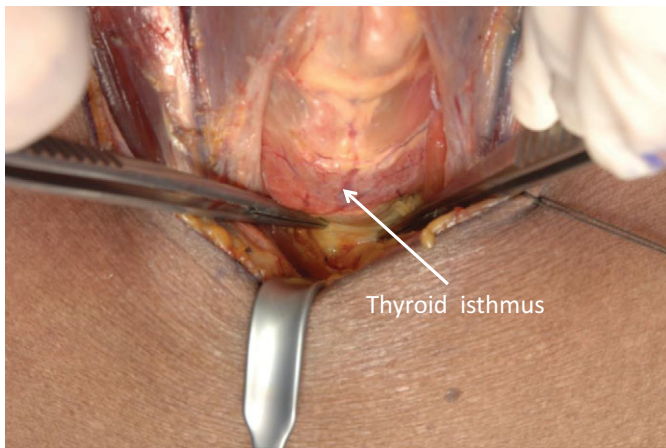


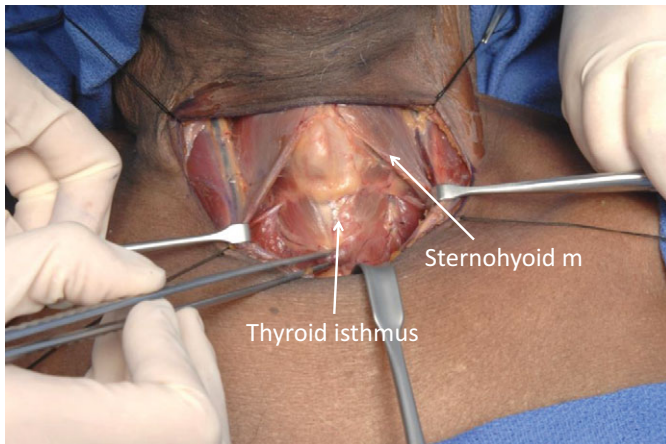
Figure 12.5 (a, b) The paired strap muscles are divided at the midline to expose the trachea, larynx, and thyroid. The most superficial strap muscle encountered is the sternohyoid muscle.

- The thyroid isthmus will often need to be divided in order to fully expose the underlying trachea and larynx. This can be accomplished using electrocautery or suture ligation.

(a)



(b)



(c)

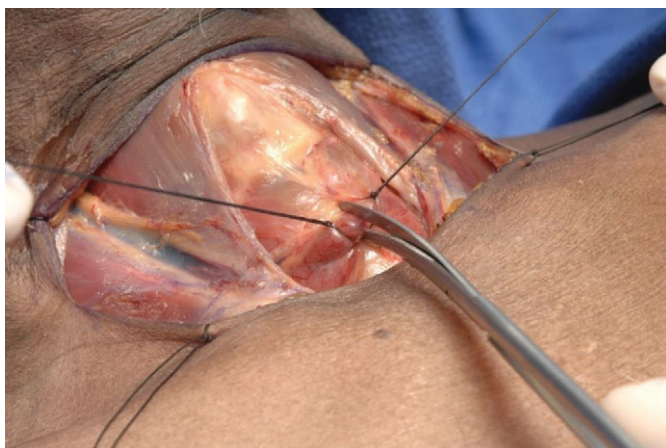


Figure 12.6 The thyroid gland overlies the trachea (a). The size and location of this gland is variable amongst patients. If the thyroid isthmus is obstructing visualization of the trachea, it can be divided using Bovie electrocautery or suture ligation (b, c).

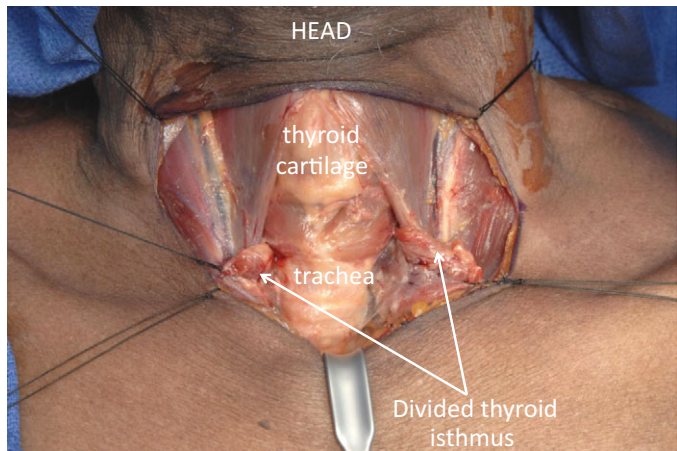


Figure 12.7 Division of the thyroid gland provides unparalleled exposure of the trachea.

- The larynx may also be accessed from the collar incision provided a generous superior extension of the subplatysmal flap is performed.
- **Sternocleidomastoid Incision**
 - In patients with suspected associated injuries to the esophagus or major vessels, an incision over the anterior border of the sternocleidomastoid is preferable (reference [Chapter 13](#), Cervical Esophagus for images).
 - A neck incision is made through the skin and the platysma is divided.
 - The sternocleidomastoid muscle is retracted laterally to expose the carotid sheath.
 - Division of the omohyoid muscle allows exposure of the deep structures of the neck.
 - The carotid sheath is then retracted laterally with the sternocleidomastoid muscle to expose the trachea and esophagus.
 - Bilateral sternocleidomastoid incisions may be necessary for penetrating transcervical wounds.
- **Sternotomy**
 - For lower tracheal injuries, a median sternotomy or partial upper sternotomy may be necessary. This will usually be an inferior extension of the sternocleidomastoid or collar incision.
 - A midline incision is made from the sternal notch to the xyphoid process (see sternotomy chapter for images).
 - The midpoint of the sternum is identified and scored using electrocautery.
 - Superiorly, the interclavicular ligament is divided and the undersurface of the sternum is bluntly dissected away from the pericardial sac.
 - The sternum is divided using an electric saw or Lebsche knife, providing exposure to the substernal trachea.

- For inferior tracheal injuries, the left brachiocephalic vein may need to be divided for additional exposure.

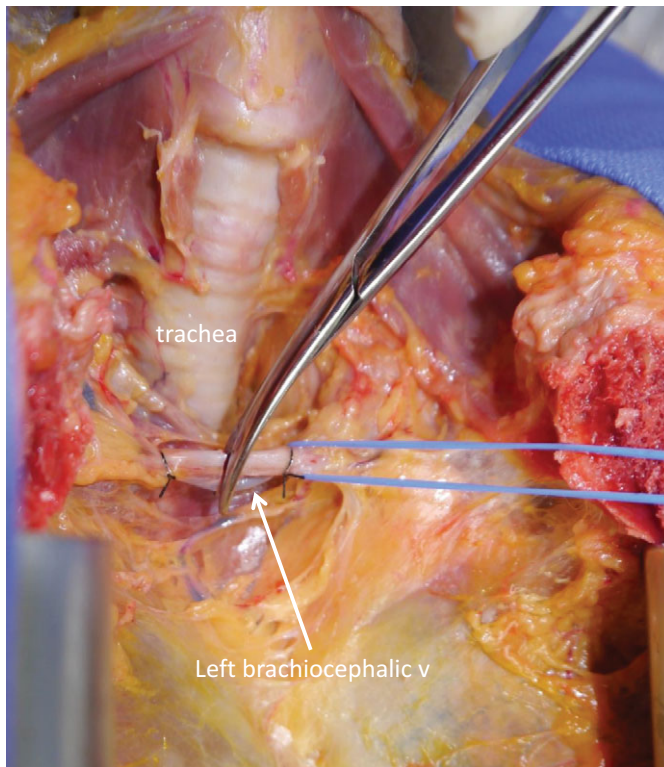


Figure 12.8 To access the lower trachea and carina, the left brachiocephalic vein may need to be divided to provide additional exposure.

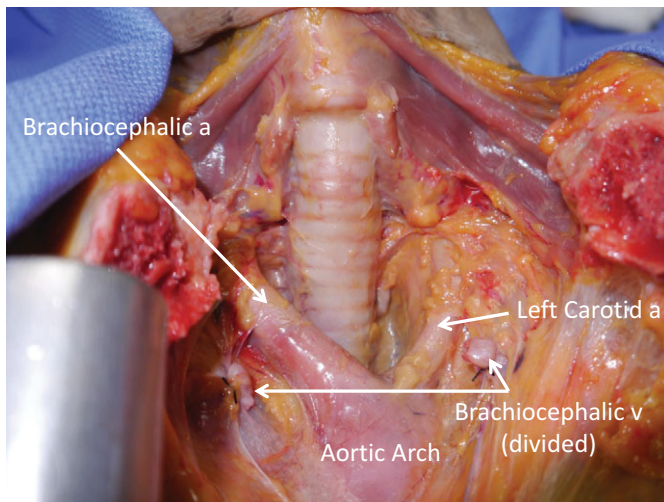


Figure 12.9 The addition of a sternotomy and division of the left brachiocephalic vein provides excellent exposure to the lower trachea. The aortic arch and brachiocephalic artery can be gently retracted to access the lower trachea. For injuries at the carina or bronchi, a thoracotomy incision may be required.

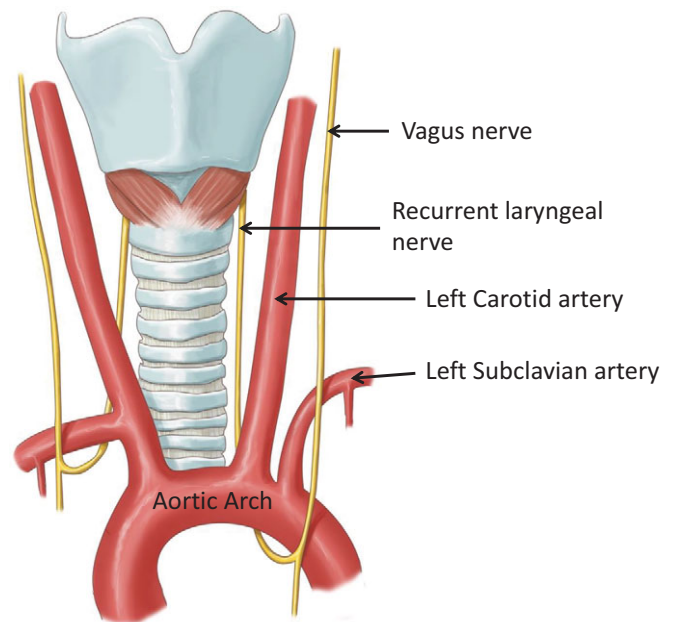


Figure 12.10 The trachea is a midline structure and the lower trachea may be accessed above the aortic arch between the brachiocephalic and left carotid arteries. The recurrent laryngeal nerves (RLN) run laterally along the trachea-esophageal groove. The right RLN branches off the vagus nerve under the right subclavian artery, the left RLN courses under the aortic arch.

Repair

- Most penetrating laryngotracheal injuries without significant tissue loss can safely be managed by primary repair and without a tracheostomy.
- All devitalized tissue must be debrided prior to repair or reconstruction.
- Most injuries to the trachea can be primarily repaired using simple, interrupted, absorbable suture.

(a)

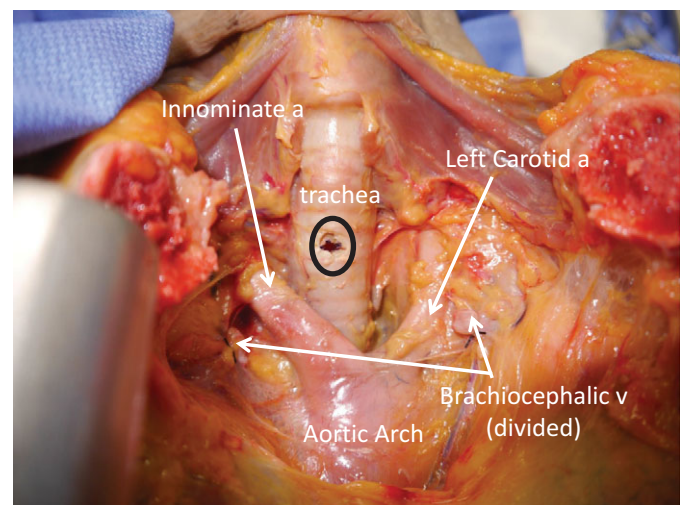
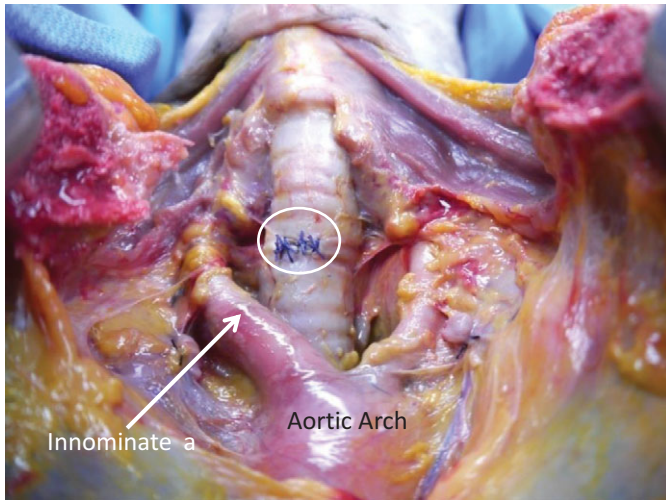


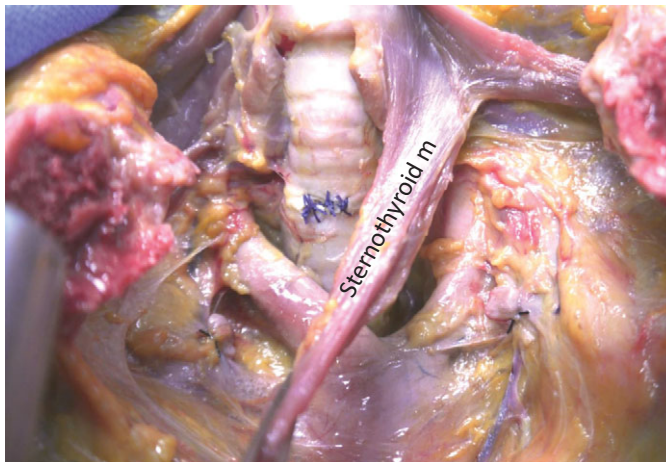
Figure 12.11 Simple penetrating wound to the trachea (black circle). Exposure through a combined collar incision and median sternotomy (a). Repair with absorbable sutures (b)

(b)

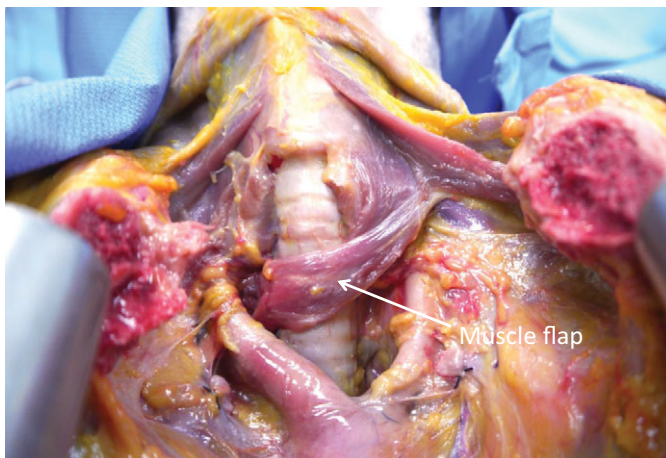
**Figure 12.11** (cont.)

- In complex injuries, the repair should be buttressed with an adjacent muscle flap. A protective tracheostomy should be considered.

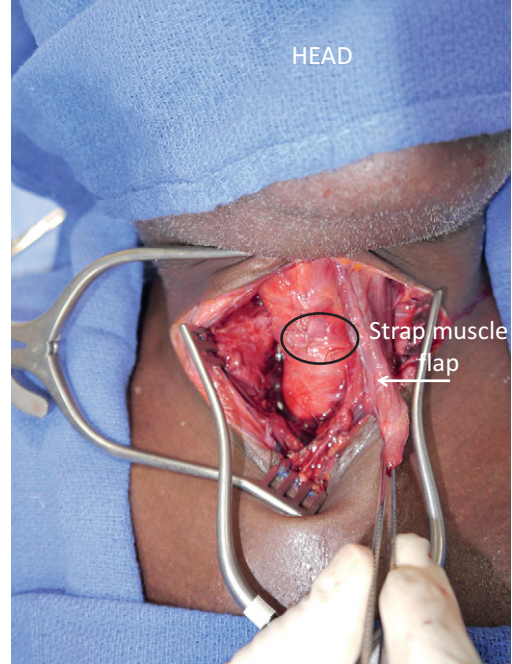
(a)



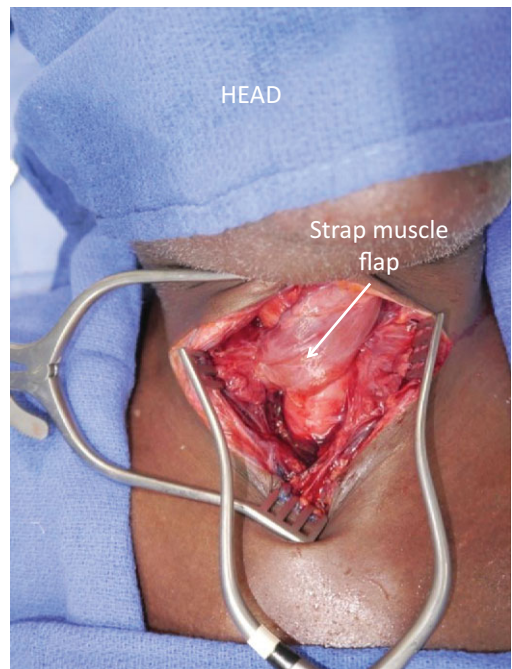
(b)

**Figure 12.12** (a) The sternothyroid muscle is mobilized as a flap to provide a buttress for the repair. (b) The muscle flap is in place covering the repair.

(c)

**Figure 12.12** (cont.)

(a)

**Figure 12.13** Complex injury repair with muscle flap (a) and protective tracheostomy (b).

(b)

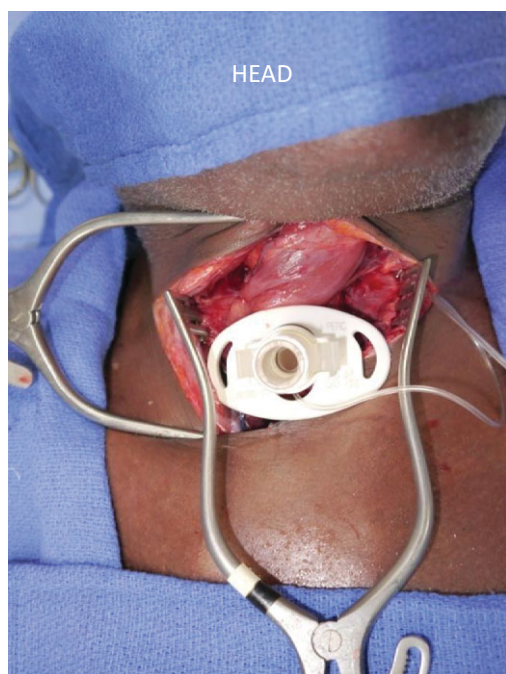
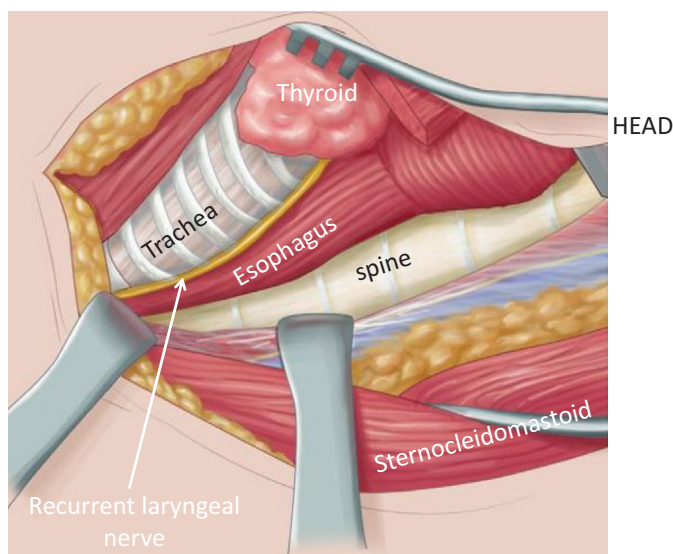
**Figure 12.13** (cont.)

Figure 12.14 Lateral view of the midline neck structures from a left sternocleidomastoid incision. The trachea is the most anterior structure. The posterior membranous portion of the trachea abuts the anterior surface of the esophagus and the recurrent laryngeal nerve runs in the trachea-esophageal groove. Posterior to the esophagus are the vertebral bodies. The carotid sheath and sternocleidomastoid muscle are retracted laterally to provide this exposure.

- Prior to placing sutures through the trachea, it is important to deflate the endotracheal balloon in order to avoid damage or inclusion of the balloon in the repair.

- If the injury is not amenable to primary repair, a tracheal resection and anastomosis is performed.
 - In this case, the trachea is mobilized superiorly and inferiorly using sharp dissection to minimize potential recurrent laryngeal nerve injury.
 - The injured section of trachea is sharply debrided.
 - The trachea is reapproximated using interrupted 3-0 absorbable sutures.
 - The endotracheal tube cuff is advanced and inflated distal to the repair or, in the event of a complex repair, a tracheostomy may be performed.
 - All efforts should be made for early postoperative extubation.

In extensive injuries with large mucosal lacerations, displaced fractures, unstable laryngeal cartilaginous skeleton, or complete laryngotracheal separation, an otolaryngology surgeon should be involved. Many of these patients may require endolaryngeal stents or other complex repairs.

Pitfalls

- Once the platysma is divided, care must be taken to ligate or avoid the paired anterior jugular veins as injury can result in excess blood loss or staining of the operative field.
- The recurrent laryngeal nerve runs vertically on either side of the trachea along the tracheoesophageal groove. Injury to this nerve is more common with the local use of electrocautery or if the dissection planes are unclear.
- In the setting of tracheal injury, many patients use all accessory compensatory mechanisms to maintain air exchange. With induction, the patient may rapidly decompensate as the loss of muscle tone can collapse the remaining structure of the airway and result in complete airway loss. For this reason, the operating room is often the best location to attempt definitive airway and awake intubation is often preferable with supplies for a surgical airway at hand (See [Chapter 2](#) Cricothyroidotomy).
- During mobilization of the trachea, it is important to minimize the superior and inferior extent of dissection, in order to preserve tracheal blood supply.
- In most major laryngotracheal injuries, especially those with associated vascular injuries, the patient aspirates significant amounts of blood. It is strongly recommended that a fiber-optic bronchoscopy is performed to clear the bronchial tree at the end of the operation.

Cervical Esophagus

Elizabeth R. Benjamin and Kenji Inaba

Surgical Anatomy

- The cervical esophagus extends from the cricopharyngeus muscle into the chest to become the thoracic esophagus.
- The external landmark of the pharyngoesophageal junction is the cricoid cartilage. On esophagoscopy, this is at 15 cm from the upper incisors.
- The esophagus lacks a serosal layer and consists of an outer longitudinal and inner circular muscle layer.
- The cervical esophagus is approximately 5–7 cm long and lies posterior to the cricoid cartilage and trachea and anterior to the longus colli muscles and vertebral bodies. It is flanked by the thyroid gland and carotid sheath on either side.
- Blood supply is primarily from the inferior thyroid artery, although significant collateral circulation exists.
- The recurrent laryngeal nerves lie on either side of the esophagus in the tracheoesophageal groove.

General Principles

- Esophageal trauma often presents with other associated injuries including carotid, jugular, tracheal, and thyroid injury. As such, neck exploration for suspected injury of any of these structures must always include evaluation of the cervical esophagus.
- Early clinical signs and symptoms of cervical esophageal injury include odynophagia, hematemesis, and subcutaneous emphysema. Late signs include fever, erythema, leukocytosis, swelling and/or abscess formation, and ultimately spreading of the infection along the precervical plane leading to mediastinitis.
- Workup of a stable patient with potential esophageal injury includes a neck CT, gastrografin, followed by barium swallow study, and/or esophagoscopy.
- Management of esophageal injuries hinges on early debridement and repair or, if delayed, drainage, broad-spectrum antibiotics, and nutritional support.

Special Instruments

- In addition to a standard instrument tray for the neck exploration, a self-retaining Weitlaner or cerebellar retractor will be necessary.

- If there is concern for thoracic extension of the esophageal injury, the surgeon should be prepared to perform a high right thoracotomy to expose the proximal thoracic esophagus.
- A rigid and flexible endoscope should be available for intraoperative esophagoscopy, if necessary.

Patient Positioning

- Provided cervical spine injury has been ruled out, the patient is positioned in a supine position with the head turned to the right. A bump is placed under the patient's shoulder to allow gentle neck extension for improved exposure. When possible, the arms are tucked.

Incisions

- Standard exposure of the cervical esophagus is through a left-sided oblique neck incision, running along the anterior border of the sternocleidomastoid muscle.
- Depending on associated injuries, a collar incision, bilateral sternocleidomastoid incisions, a sternotomy, or a supraclavicular extension may be necessary.

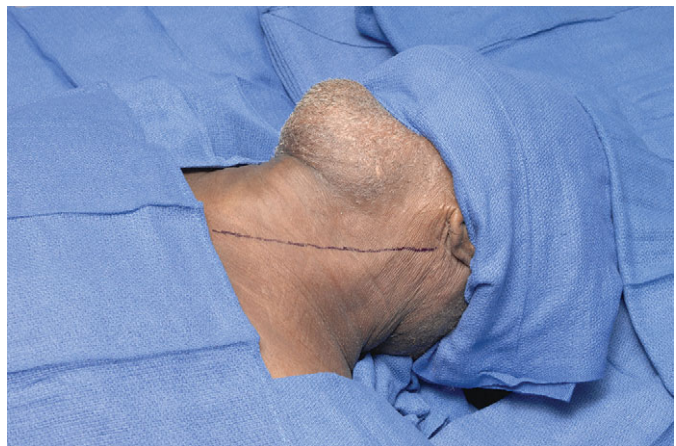


Figure 13.1 To access the cervical esophagus, the patient's head is turned to the right and the neck is extended. The incision is made along the anterior border of the sternocleidomastoid muscle.

Esophageal Exposure

- An incision is made through the skin and dermis, and the platysma is divided.
- The sternocleidomastoid muscle is retracted laterally to expose the sternohyoid, omohyoid, and underlying carotid sheath.
- Division of the omohyoid muscle allows for exposure of the deep structures of the neck.

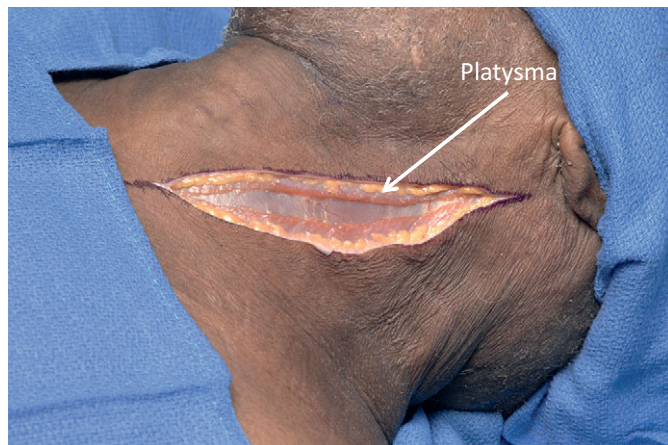


Figure 13.2 The platysma muscle is divided using sharp dissection or Bovie electrocautery. This layer is reapproximated with absorbable suture upon closure.

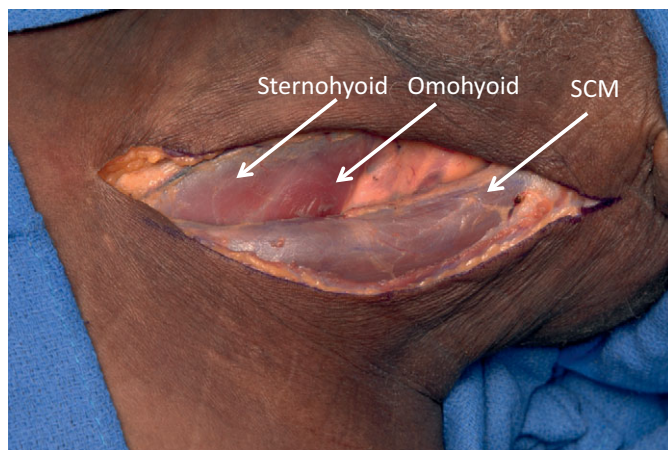


Figure 13.3 The sternocleidomastoid muscle (SCM) runs tangentially across the neck and must be retracted laterally to expose the vascular and aerodigestive structures of the neck. The omohyoid and sternohyoid muscles are medial and just deep to the SCM.

- The carotid sheath is then retracted laterally with the sternocleidomastoid muscle, while the trachea and thyroid are retracted medially to expose the cervical esophagus.

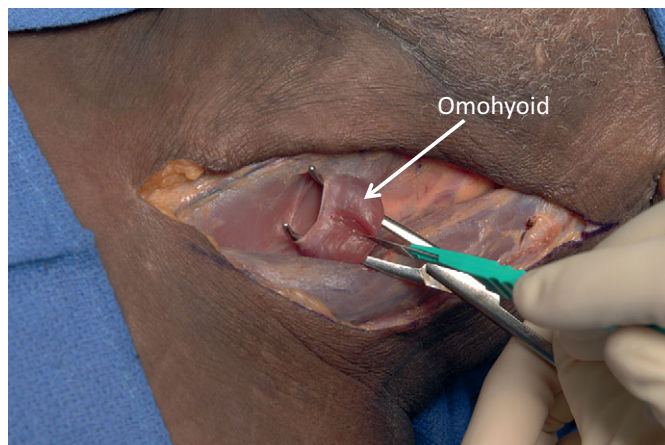
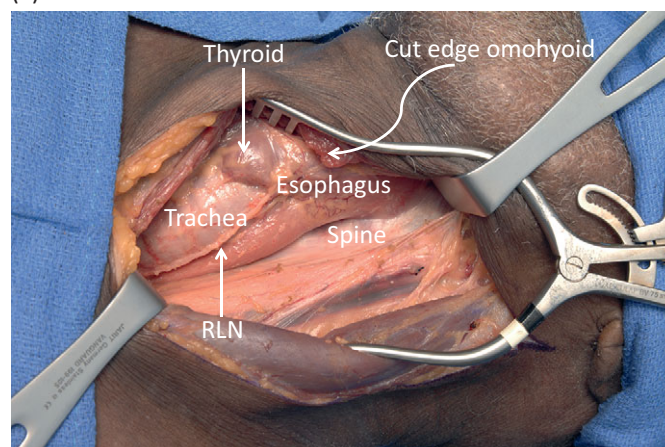


Figure 13.4 The omohyoid is isolated and divided in order to expose the deep structures of the neck.

(a)



(b)

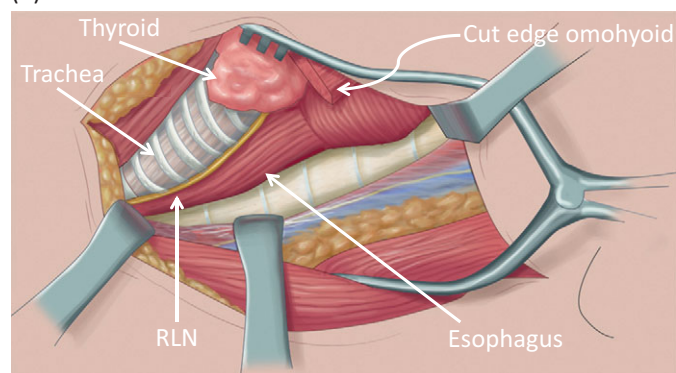
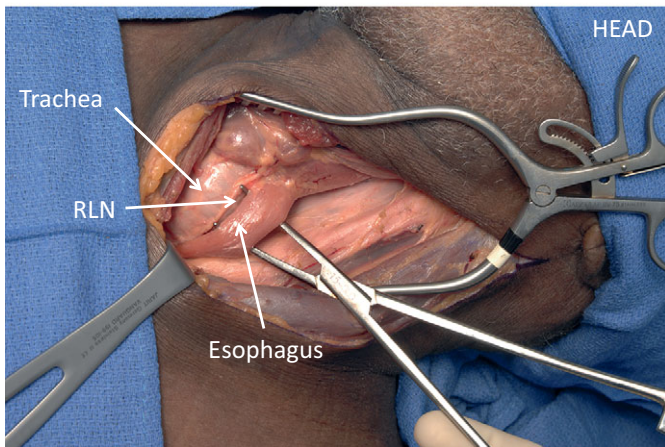


Figure 13.5 The thyroid is anterior on the trachea and can be retracted medially. With the omohyoid divided, the tracheoesophageal groove is exposed. The recurrent laryngeal nerve (RLN) runs in this groove, anterior to the cervical esophagus. From this exposure, the esophagus is directly posterior and left lateral to the trachea and anterior to the spine (**a, b**).

- A nasogastric tube, if in place, can be of assistance in palpating the esophagus.
- The middle thyroid vein, and often, the inferior thyroid artery, may be ligated and divided to gain better access to the esophagus.
- Retraction alone may provide adequate exposure for injury identification and repair. If further mobilization is required, with the aid of a nasogastric tube or bougie, the esophagus can be bluntly dissected circumferentially and manipulated by passing a ½ in. Penrose drain or vessel loop around the structure for additional retraction.

(a)



(b)

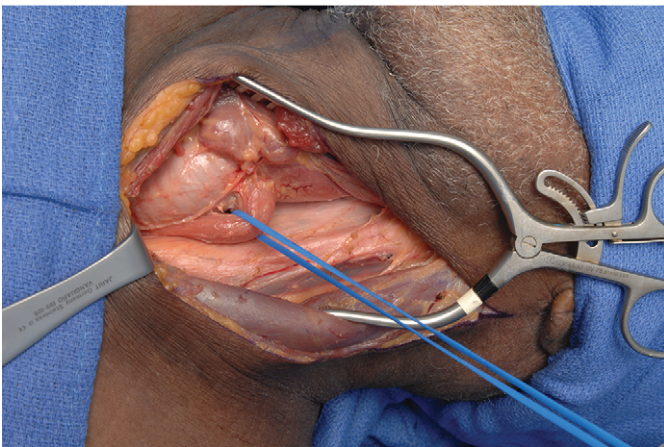
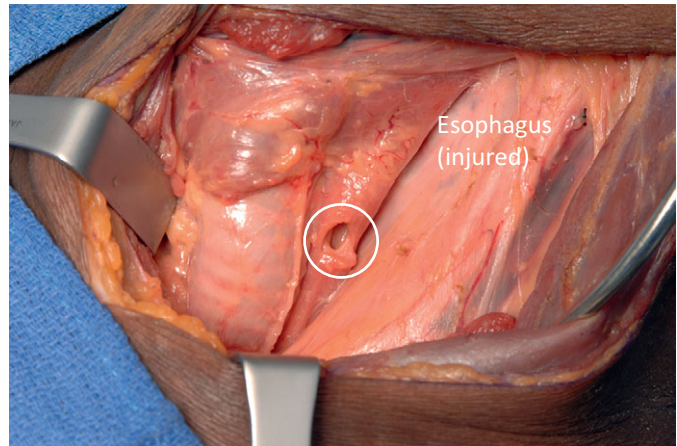


Figure 13.6 Additional exposure can be obtained by gentle retraction of the esophagus.

Repair

- Traumatic cervical esophageal injury can often be identified on gross inspection. Intraoperative endoscopy or esophageal insufflation with air or methylene blue can also be useful adjuncts to identify an injury.

(a)



(b)

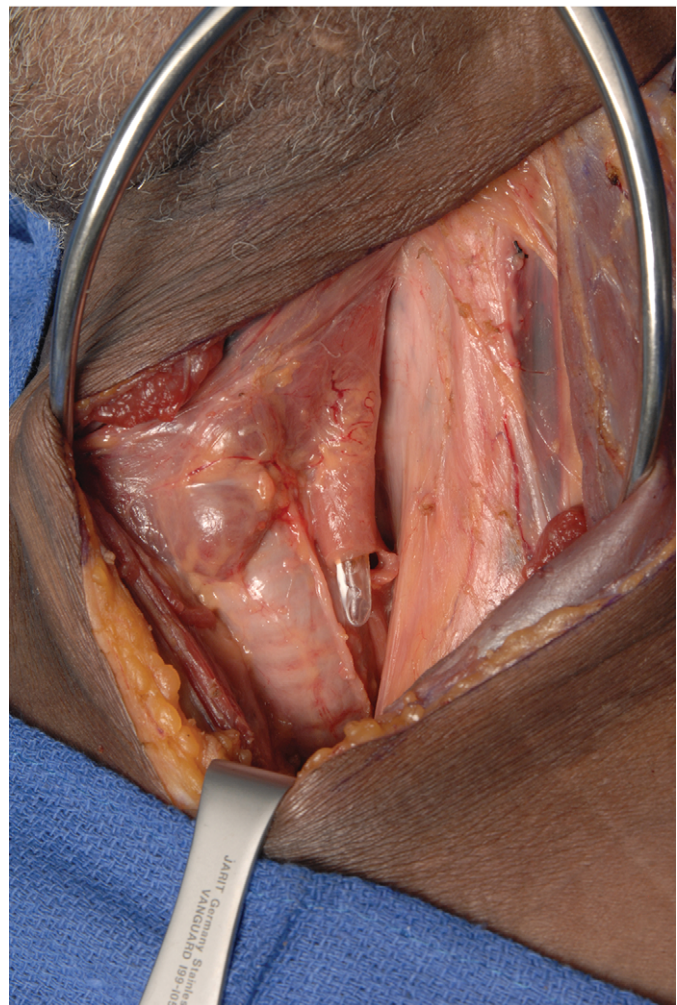


Figure 13.7 A full thickness defect of the left lateral wall of the cervical esophagus (a) with a nasogastric tube in place with the tip at the level of the defect (b).

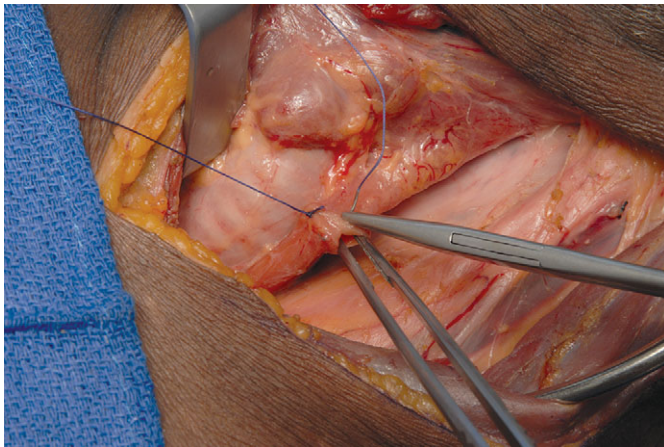


Figure 13.8 Esophageal injuries are repaired with absorbable suture in one or two layers. Repair must include reapproximation of the mucosa.

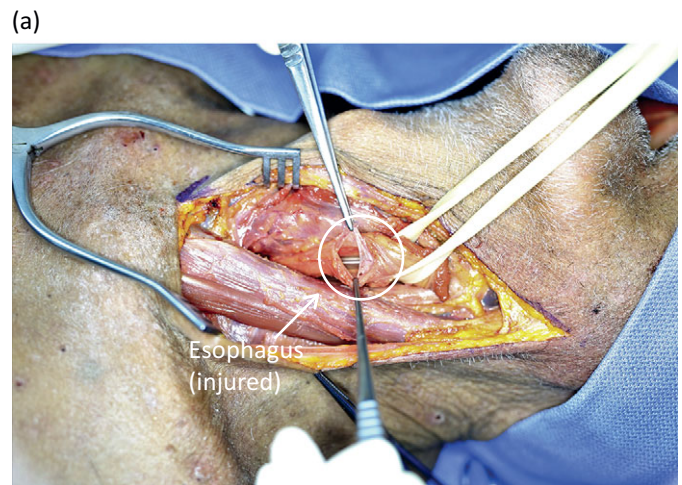
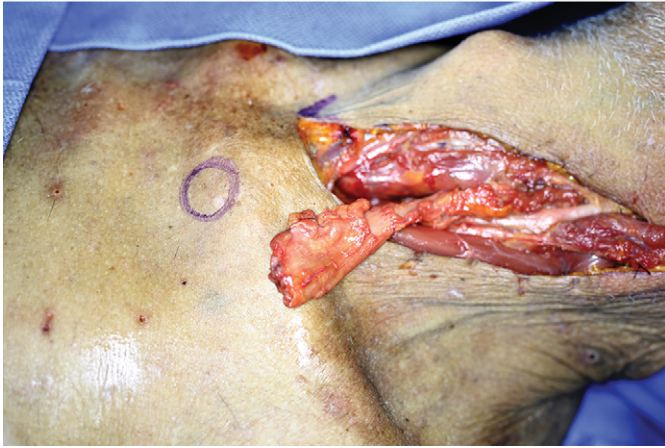


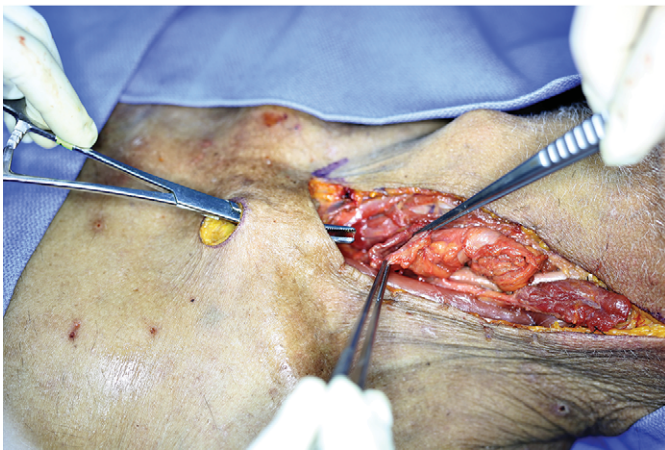
Figure 13.9 Destructive injury to the cervical esophagus (a). Neighboring strap muscle can be mobilized to provide a buttress or be used to isolate the esophageal repair (b).

- The majority of injuries can be repaired primarily without tension. The wound edges are first debrided of any devitalized tissue, and the mucosal defect is identified. The injury can be closed in one or two layers, however, when possible, a two-layer closure using absorbable suture is recommended. The inner layer should reapproximate mucosal edges.
- Neighboring strap muscle can be used to buttress the esophageal repair and isolate the suture line from associated tracheal or vascular injuries.
- A closed suction drain is typically placed outside the esophageal repair. This drain is removed on POD #5–7 after anastomotic leak is ruled out by contrast study.
- In destructive injuries that are unable to be primarily repaired, wide drainage, possible cervical esophagostomy, and delayed interposition graft are treatment options.
- When a cervical esophagostomy is needed, the distal cervical esophagus is dissected and transected. The end is delivered through a separate incision and matured. Care is taken to provide surrounding skin topography to accommodate an appliance.

(a)



(b)



(c)

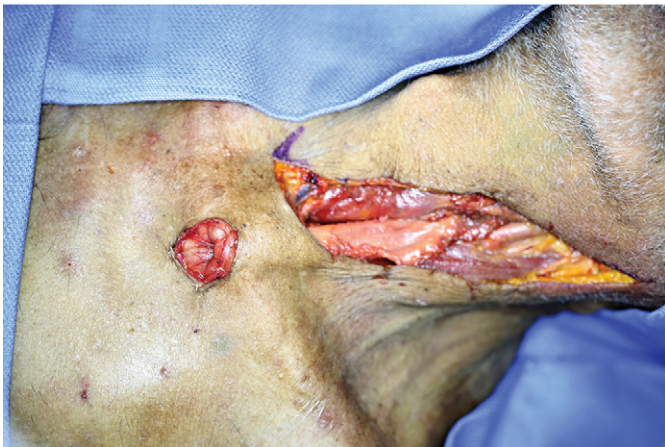


Figure 13.10 In cases where a cervical esophagostomy is needed, the cervical esophagus is transected distally (a) and the cut end is fed through a separate incision (b) and matured into an ostomy (c).

Pitfalls

- The recurrent laryngeal nerve runs in the tracheoesophageal groove and can easily be injured during exposure of the esophagus.

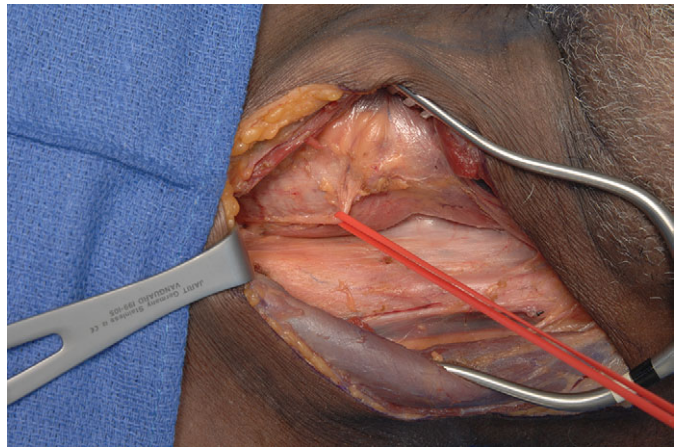


Figure 13.11 At the levels of the cervical esophagus, the recurrent laryngeal nerve runs along the tracheoesophageal groove.

- The posterior membranous portion of the trachea is very delicate and injury can easily occur with dissection of the trachea off the anterior esophagus.

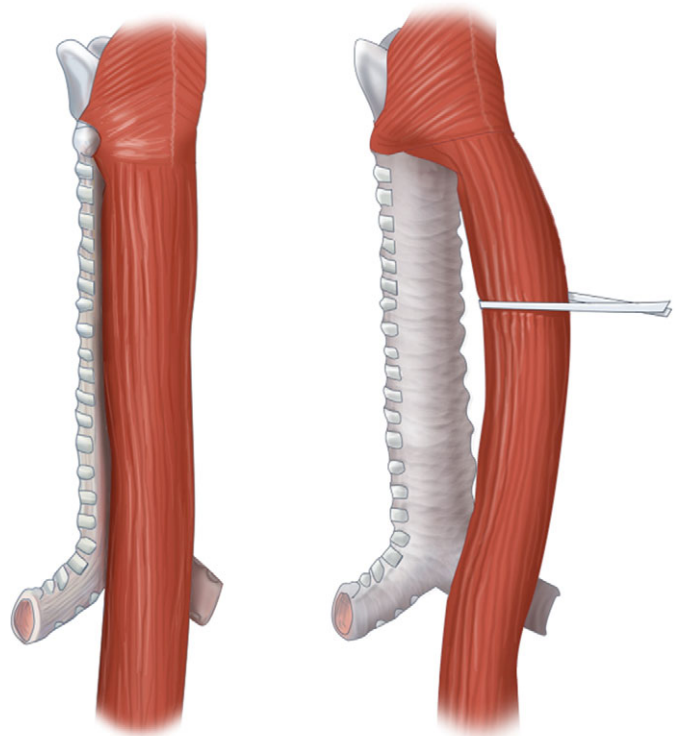


Figure 13.12 The esophagus lies directly behind the trachea and shares a border with the membranous portion of the trachea. Care must be taken not to injure the membranous portion of the trachea, when dissecting the anterior border of the esophagus.

- The inner layer of the esophageal repair must reapproximate mucosal edges to minimize the rate of postoperative leak.
- Care must be taken with the outer layer not to cause narrowing of the esophagus. It is often helpful to close these injuries over a nasogastric tube or bougie.

General Principles of Chest Trauma Operations

Demetrios Demetriades, Matthew J. Forestiere, and Rondi Gelbard

Surgical Anatomy

The following are the major muscles that will be encountered and may be divided during thoracic operations for trauma.

- Anterior Chest Wall: Pectoralis major and pectoralis minor muscles

Pectoralis major muscle: It originates from the anterior surface of the medial half of the clavicle, the anterior surface of the sternum, and the cartilages of all the true ribs (1–7 ribs). The 5-cm wide tendon inserts into the upper humerus.

Pectoralis minor muscle: It arises from the third, fourth, and fifth ribs, near their cartilages, and from the

aponeuroses over the intercostal muscles. It inserts into the coracoid process of the scapula.

- Lateral Chest Wall: Serratus anterior muscle

Serratus anterior muscle: It originates from the lateral part of the first eight to nine ribs and inserts into the medial aspect of the scapula.

- Posterior Chest Wall: Latissimus Dorsi

Latissimus Dorsi muscle: It originates from the spinal processes of the lower thoracic spine and the posterior iliac crest and inserts into the upper portion of the humerus.

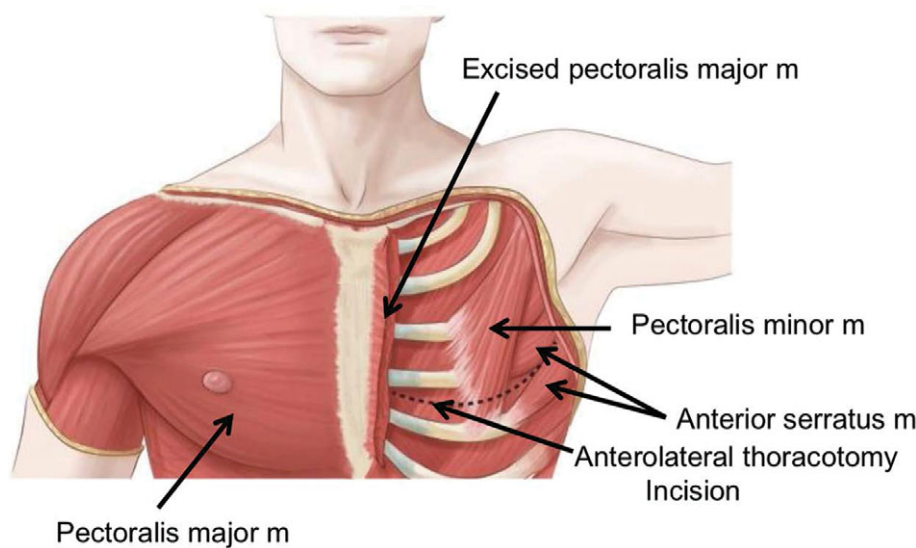


Figure 14.1 The pectoralis major and pectoralis minor muscles in the anterior chest wall and the serratus anterior on the lateral chest wall may be divided during anterolateral thoracotomy.

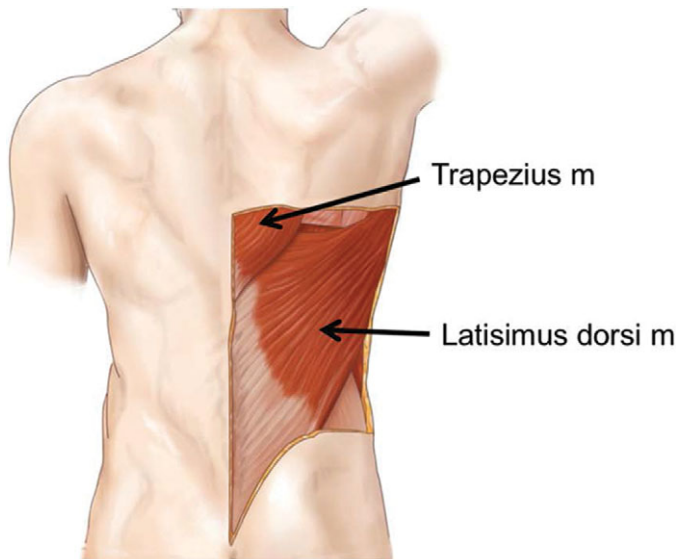


Figure 14.2 The latissimus dorsi muscle is the main muscle encountered and divided during a posterolateral thoracotomy.

General Principles

- In order to preserve chest wall function, muscle-sparing techniques should be utilized whenever possible. Excessive rib retraction should be avoided to prevent rib fractures, and all ribs should be preserved when possible.
- The thoracic wall structures should be closed by reapproximating the divided muscles in multiple layers.
- Avoid over-approximating the ribs in order to reduce postoperative pain.
- Preoperative placement of a double-lumen endotracheal tube or a bronchial blocker allows isolation of the ipsilateral lung and facilitates the exposure of posterior mediastinal structures, such as the descending thoracic aorta and the esophagus.

Positioning

In hemodynamically unstable patients, often there is no time for special positioning and the patient is placed in the standard supine position.

Median Sternotomy/Anterolateral Thoracotomy/Clamshell

- Supine position, abducted arms

Posterolateral Thoracotomy

- The patient is placed in a lateral decubitus position with the hips secured to the table by wide adhesive tape. Bean bags should be used to provide additional support.
- The lower leg is flexed at the knee, while the upper leg is straight and a pillow is placed between the knees.
- A rolled sheet is placed under the axilla to support the shoulder and upper thorax.

- The arm on the side of the thoracotomy is extended forward and upward (praying position) and placed in a padded-grooved arm holder in line with the head.
 - Overextension can lead to brachial nerve injury.
- The lower arm is extended and placed on a board at a 90° angle.

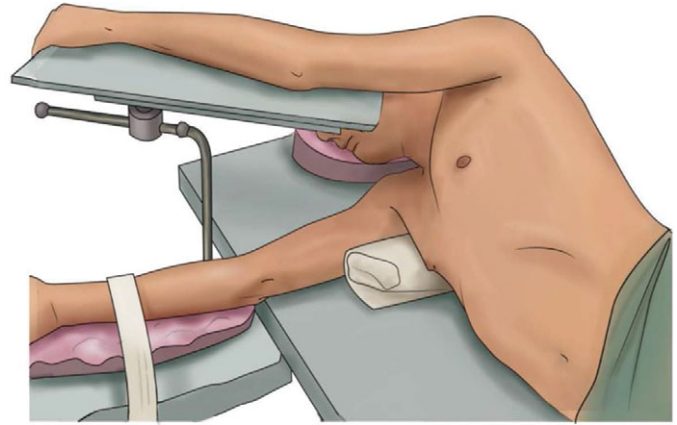


Figure 14.3 Positioning of a patient for a posterolateral thoracotomy taking care to protect and pad both arms and the decubitus axilla.

Incision(s)

The selection of incision should be based on the clinical condition of the patient, the location of the operation (emergency room versus operating room), the need for thoracic aortic cross-clamping, the location of any penetrating injuries, and the suspected injured organs. Incisions such as a posterolateral thoracotomy requiring special time-consuming positioning of the patient should be avoided in the unstable patient.

Median Sternotomy

- It is the incision of choice in penetrating injuries to the anterior chest with suspected cardiac or upper mediastinum great vessel injury.
 - It provides good exposure of the heart, the anterior mediastinal vessels, both of the lungs, the middle to distal trachea, and left main stem bronchus. It is quick to perform, bloodless, and causes less postoperative pain and fewer respiratory complications than a thoracotomy.
 - It does *not* provide good exposure of the posterior mediastinal structures and does not allow adequate access for cross-clamping of the thoracic aorta for resuscitation purposes.
- The incision is made over the center of the sternum, extending from the suprasternal notch to the xiphoid and is carried down to the sternum.
- The sternum is scored in the midline with electrocautery to direct the saw or the Lebsche knife, which is then used to divide the sternum.

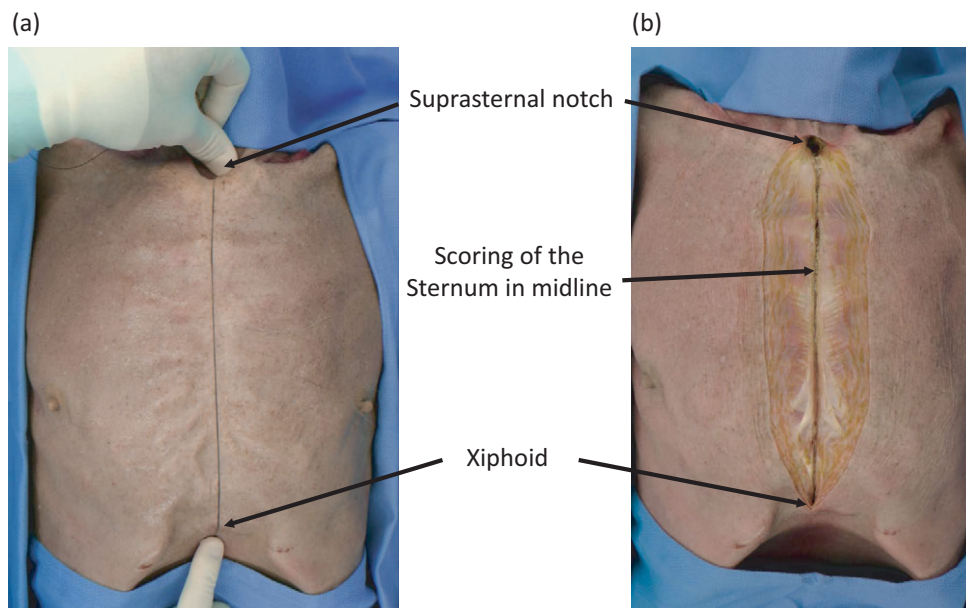


Figure 14.4 (a) The median sternotomy incision extends from the suprasternal notch to the xiphoid and (b) is carried down to the sternum. The sternum is scored with a knife or electrocautery in the midline to direct the sternal saw or Lebsche knife.

- The interclavicular ligament at the suprasternal notch is cleared from its attachment to the sternum using a combination of cautery and blunt dissection, always staying close to the bone to avoid injuring the underlying vessels.
- Confirm clearance of the posterior wall of the suprasternal notch by passing the index finger behind the manubrium.
 - Note that the pneumatic saw does not work in the presence of soft tissues!

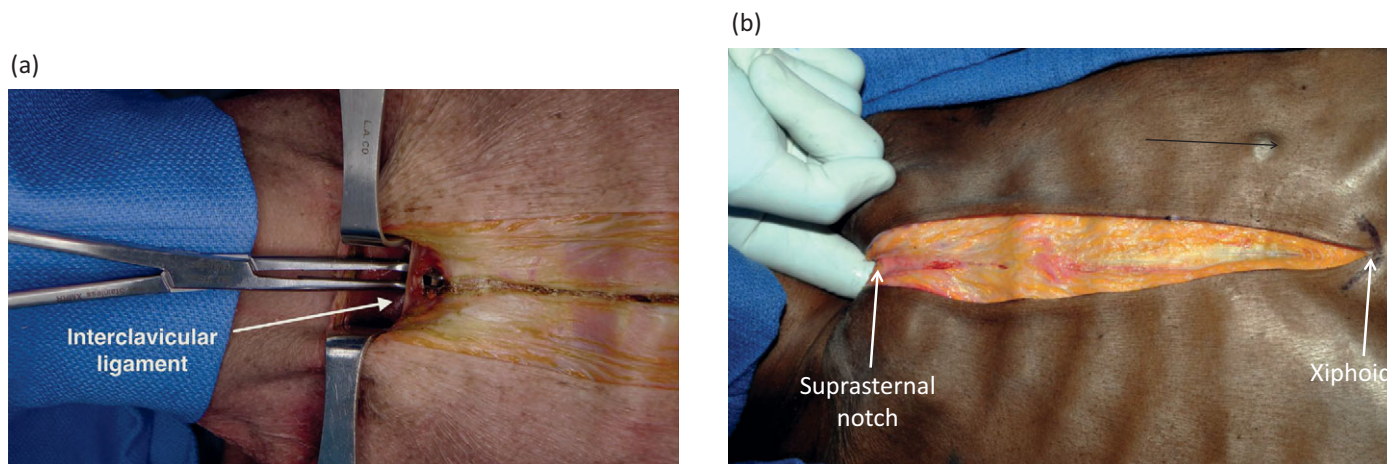


Figure 14.5 (a) The interclavicular ligament at the suprasternal notch is cleared from its attachment to the sternum using a combination of cautery and blunt dissection. (b) Clearance of the soft tissues is confirmed by passage of the index finger under the manubrium.

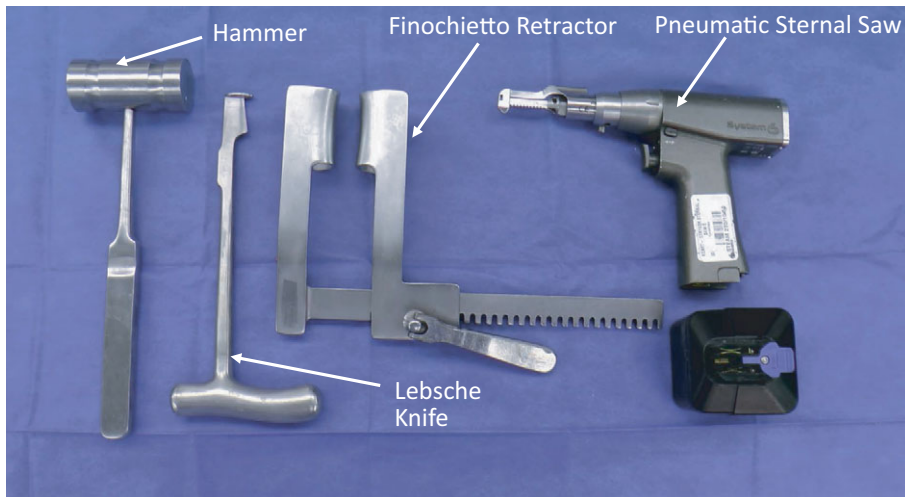
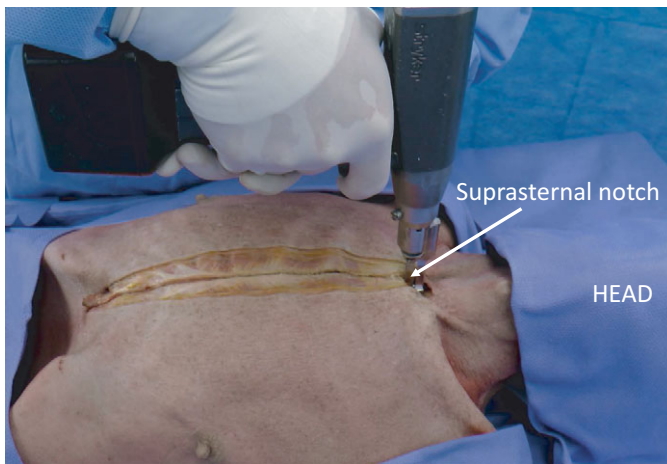


Figure 14.6 Essential instruments needed for median sternotomy – Lebsche knife, Finochietto retractor, and pneumatic sternal saw.

(a)



(b)

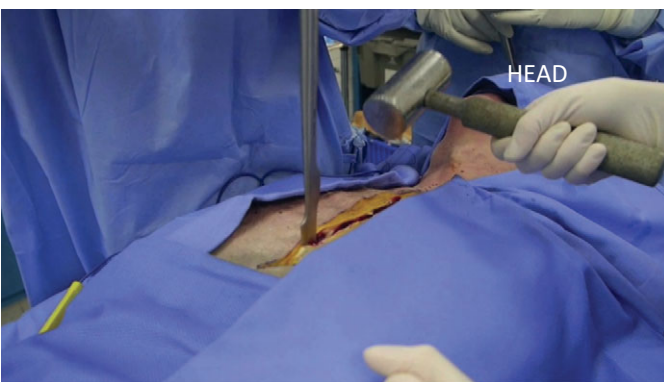


Figure 14.7 (a) Division of the sternum with the pneumatic saw, from suprasternal notch to the xiphoid. (b) Division of the sternum with the Lebsche knife and hammer.



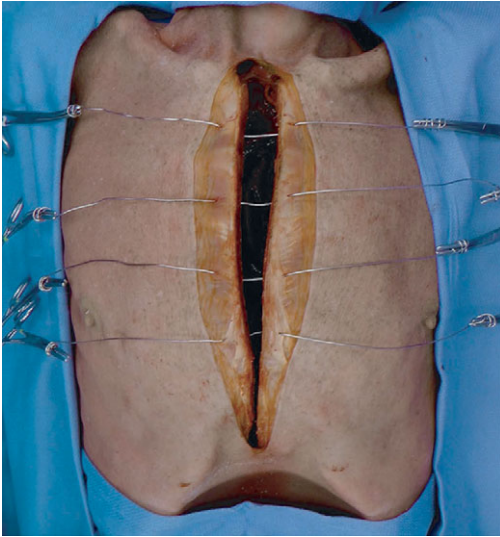
Figure 14.8 When placing the Finochietto retractor, you must ensure that the blades are at the upper part of the sternum so as not to fracture the weaker lower half of the sternum.

- Place the hook of the pneumatic saw or the Lebsche knife under the suprasternal notch and lift the sternum upwards.
 - Ask anesthesia to hold ventilation and divide the sternum directly in the midline, maintaining upwards traction along the entire length.
- Place the Finochietto retractor in the upper part of the sternotomy and spread the sternum.

Closure of Median Sternotomy

- Ensure good hemostasis along the divided bone edge with cautery or bone wax.
- Check for any bleeding under the sternum from the internal mammary arteries after removal of the sternal retractor.
- Place at least one water seal chest drain under the sternum, and place additional drains in chest cavities where the pleura was violated.
- Close the sternum with steel wires, using the heavy needle driver.
- Close the presternal fascia with heavy absorbable sutures.

(a)



(b)

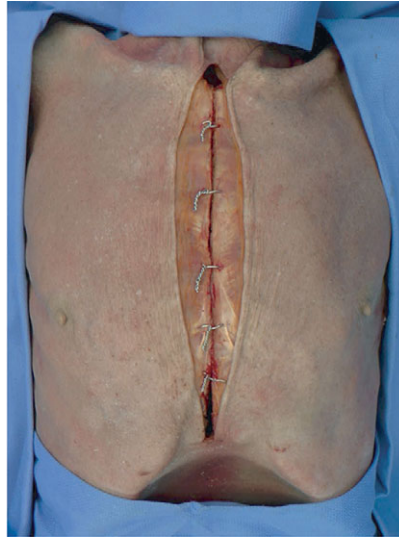
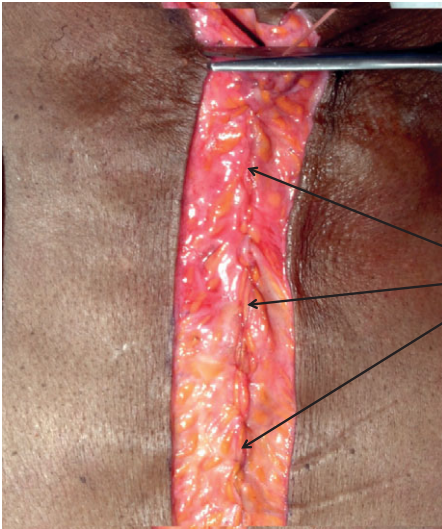


Figure 14.9 (a, b) Sternal wires are spaced evenly for the closure of the median sternotomy. (c) The presternal fascia is closed with heavy absorbable sutures.

(c)



Closed presternal
fascia

Anterolateral Thoracotomy

- This is the incision of choice for resuscitative thoracotomy, suspected injuries to the lung or the posterior heart, and cross-clamping of the aorta for resuscitation.
 - This incision, however, provides poor exposure of the anterior mediastinal vessels.
- Mark the incision with a felt tip pen prior to skin incision.
- The incision is made through the fourth to fifth intercostal space, which normally resides below the nipple in males, below the inframammary fold in females.
 - Start the incision from the parasternal border and extend to the posterior axillary line curving towards the axilla.
- The pectoralis major and pectoralis minor are encountered and divided in the anterior part of the incision.
- The serratus anterior muscle is encountered and divided in the posterior part of the incision.

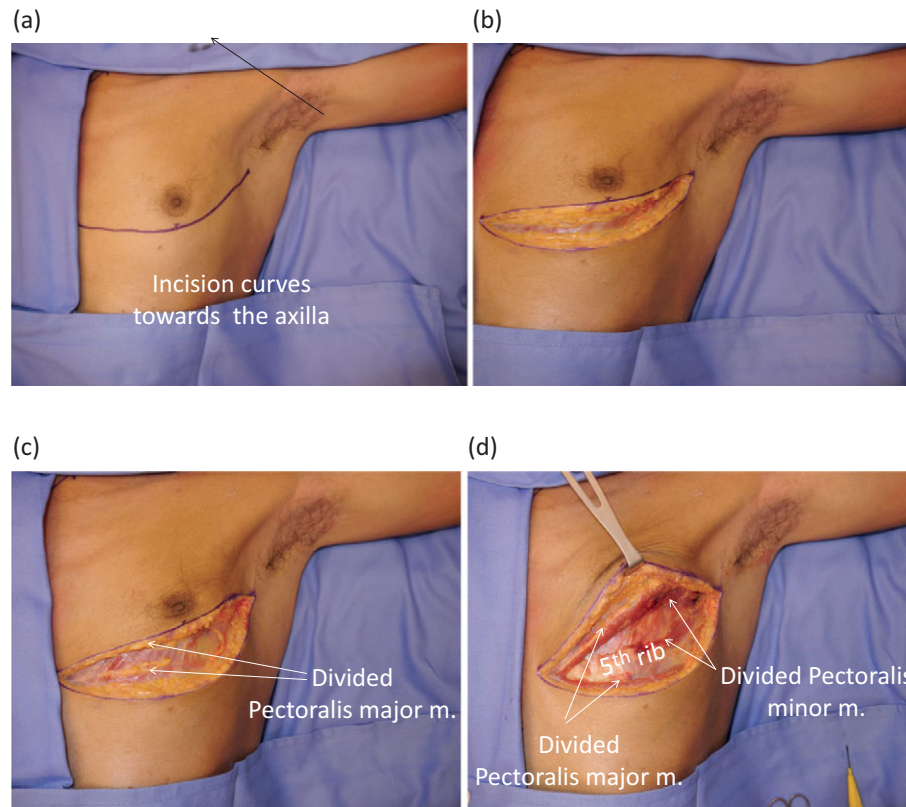
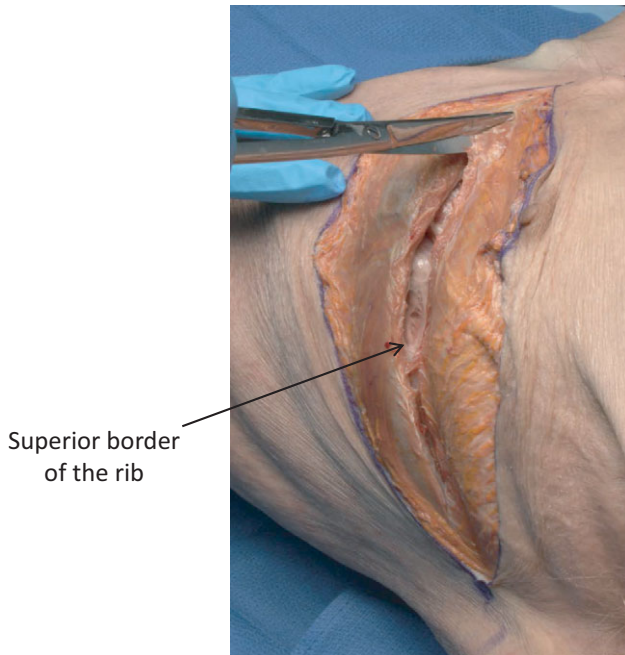


Figure 14.10 (a, b) The incision for an anterolateral thoracotomy is placed through the fourth to fifth intercostal space, starting from the parasternal border and extending to the posterior axillary line, aiming towards the axilla. (c, d) The pectoralis muscle is the first muscle encountered and divided. The lower portion of the pectoralis minor muscle is found beneath the pectoralis major muscle and divided.

- The intercostal muscles are then divided as close to the superior border of the rib as possible in order to avoid the neurovascular bundle, and the pleural cavity is entered with the use of scissors, taking care to avoid injuring the underlying inflated lung. Withholding ventilation during entry into the pleural cavity reduces the risk of iatrogenic lung injury.
- A Finochietto retractor is then placed and the ribs are spread slowly to avoid rib fractures.

(a)



(b)

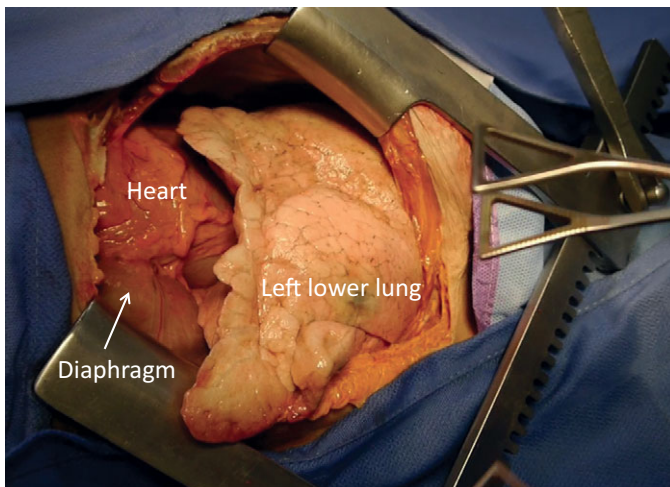


Figure 14.11 (a) The intercostal muscles are divided with the use of scissors, close to the superior border of the rib. (b) A Finochietto retractor is placed and the ribs are spread slowly to avoid rib fractures. The intrathoracic organs are exposed.

Closure of Anterolateral Thoracotomy Incision

- Insert a thoracostomy tube at the mid-axillary line.
- Close the chest wall in layers, reapproximating the divided muscles with heavy figure-of-eight absorbable sutures.

Clamshell Incision

- It is usually performed as an extension of a standard anterolateral thoracotomy to the opposite side, for suspected bilateral lung injuries, superior mediastinal vascular injuries or cardiac resuscitation, and aortic cross-clamping.
- It provides good exposure of the anterior aspect of the heart, the superior mediastinal vessels (aortic arch and branches, superior vena cava and innominate veins), and both lungs.
- The incision is made through the fourth to fifth intercostal spaces bilaterally with transverse division of the sternum, using bone cutters or heavy scissors.
- During division of the sternum, both internal mammary arteries are transected, and identification and ligation of the proximal and distal ends should be performed.

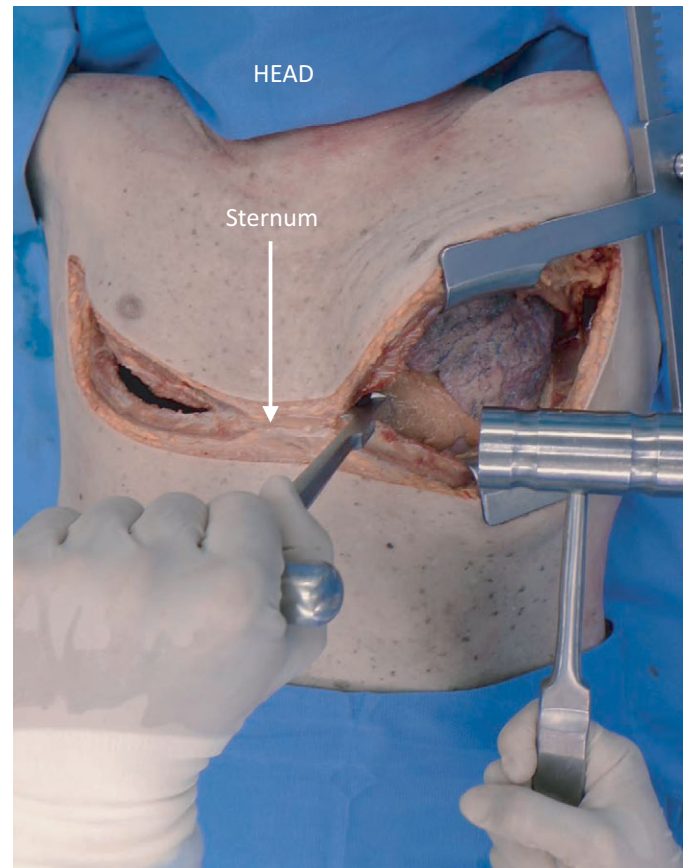


Figure 14.12 The clamshell incision is made through the fourth or fifth intercostal space bilaterally with transverse division of the sternum. The sternum can be divided with a Lebsche knife, rib cutters, heavy scissors, or trauma shears.

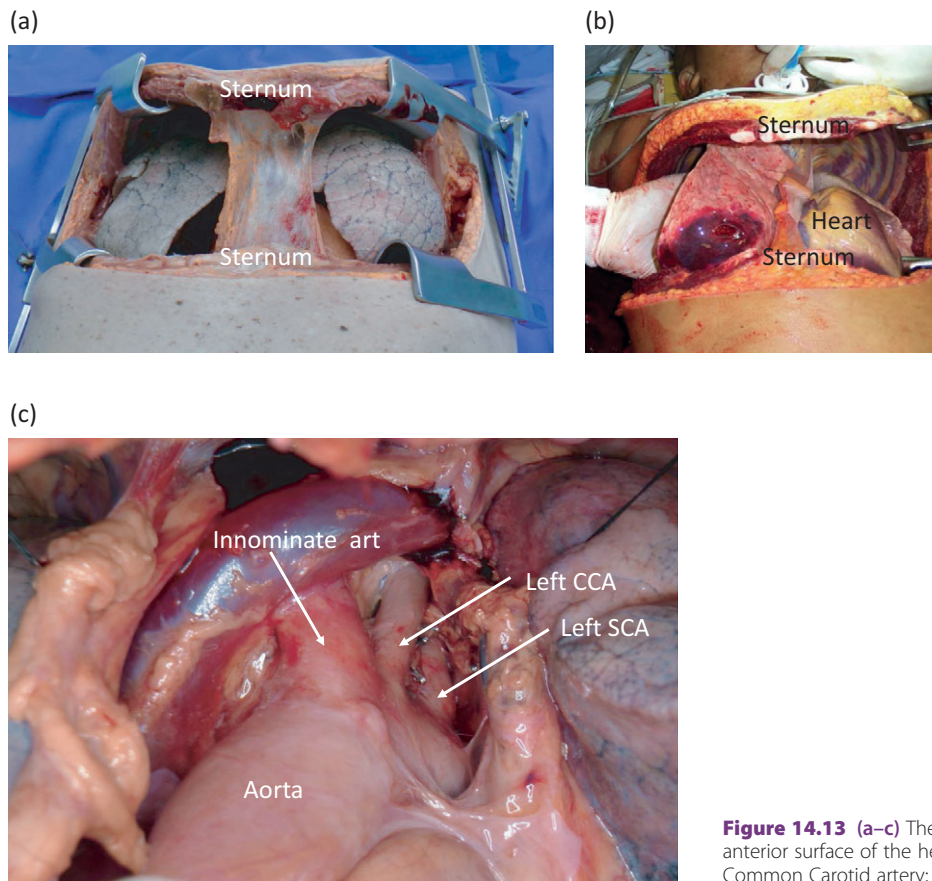


Figure 14.13 (a–c) The clamshell incision provides good exposure of the anterior surface of the heart, the mediastinal vessels, and both lungs (CCA, Common Carotid artery; SCA, Subclavian artery).

Closure of Clamshell Incision

- The divided sternum is reapproximated with steel wires and the thoracotomy incisions are closed as described above.

Posterolateral Thoracotomy

- This approach requires special patient positioning. It is usually indicated for injuries to the descending aorta, thoracic esophagus, distal trachea, and main stem bronchi.
 - A thoracotomy through the fourth or fifth intercostal space on either side allows good access to the pulmonary hilum and is considered the approach of choice for major pulmonary resections.
 - A low left posterolateral thoracotomy through the sixth or seventh intercostal space provides good exposure to the distal third of the thoracic esophagus.
 - A high right thoracotomy through the fourth intercostal space provides good access to the upper and middle esophagus.
- A curvilinear skin incision is made, extending from the anterior axillary line, coursing approximately 1–2 fingerbreadths below the tip of the scapula, and extending posteriorly and cephalad midway between the spine and the medial border of the scapula (the tip of the scapula is usually over the sixth or seventh intercostal space).

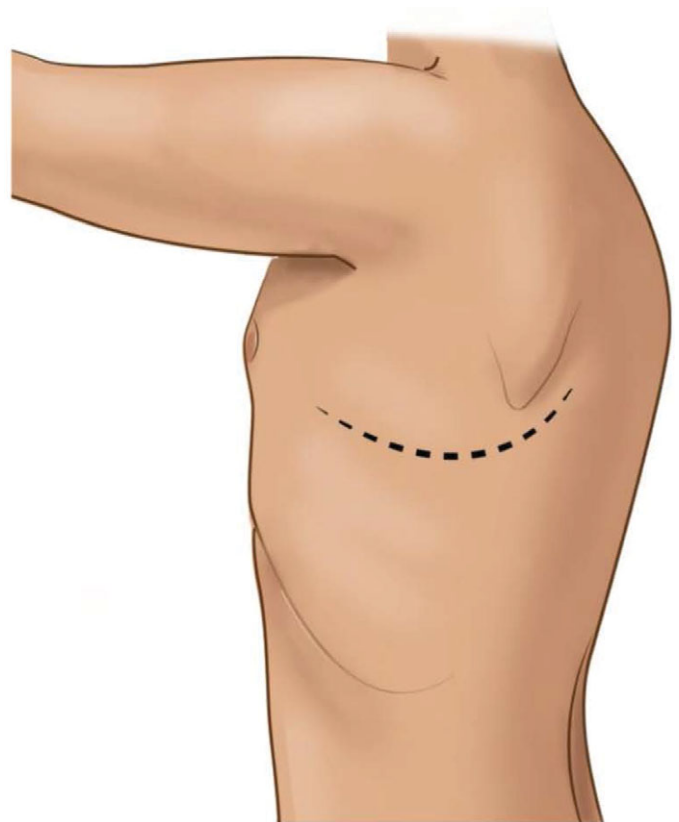


Figure 14.14 The skin incision for the posterolateral thoracotomy extends from the anterior axillary line, coursing 1–2 fingerbreadths below the tip of the scapula and extends posteriorly and cephalad midway between the spine and the medial border of the scapula.

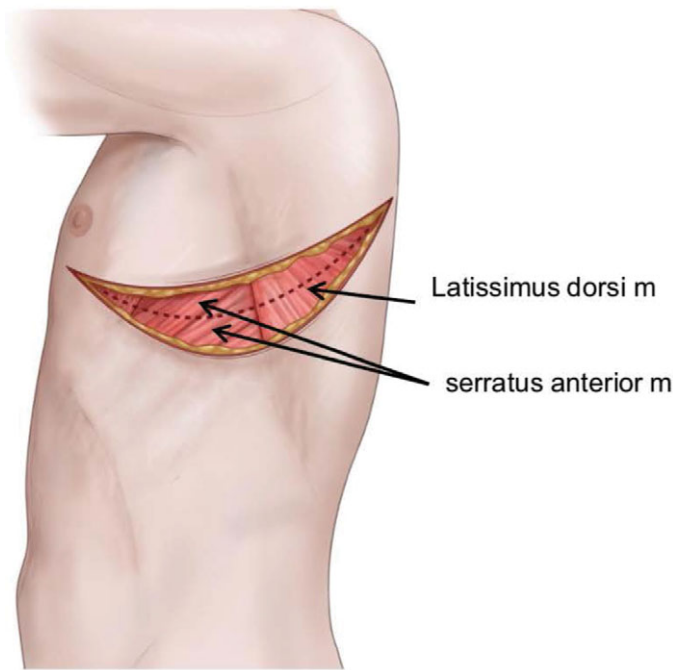


Figure 14.15 Left posterolateral thoracotomy through the sixth or seventh intercostal space. The latissimus dorsi can either be divided or spared, but the serratus anterior muscles are divided. More posteriorly, the trapezius or the rhomboid muscles may need to be divided.

- The latissimus dorsi is identified and divided in line with the incision using electrocautery.
- The serratus anterior muscle is then divided as low as possible to minimize the amount of denervated muscle.
- In the same plane posteriorly, the trapezius muscle (or more superiorly the rhomboid muscles) may need to be divided for additional exposure.
- The scapula is elevated using a scapular retractor, the appropriate intercostal space is selected and the pleural cavity is entered at the superior border of the rib, in order to avoid injuring the neurovascular bundle.
- Resection of a 3–4 cm portion of the fifth or sixth rib posteriorly improves exposure and prevents iatrogenic fracturing of the ribs.

Closure of Posterolateral Thoracotomy

- Approximation of the divided muscles and the subcutaneous tissue as described in the anterolateral thoracotomy.

Technical Pitfalls

• Sternotomy Incision

- Failure to divide the interclavicular ligament at the suprasternal notch and clear its attachments to the sternum causes malfunction of the pneumatic saw as the pneumatic saw does not work in the presence of soft tissues.
- The median sternotomy goes off midline, through the costal cartilages. This complicates the closure and increases the risk of sternal dehiscence. To avoid this problem, score the sternum in the midline with electrocautery to guide the saw or the Lebsche knife.
- The sternal retractor should not be placed in the lower part of the sternotomy. This is the weakest part of the sternum and increases the risk of sternal fracture. Place the retractor in the upper part of the median sternotomy.

• Anterolateral Thoracotomy

- If the incision does not follow the intercostal space, it makes entry into the chest cavity difficult and messy! The incision should curve upwards, directed towards the axilla.
- Excessive spreading of the rib retractor may cause rib fractures and increase postoperative pain.
- Always inspect for injury to the left internal mammary artery after removal of the retractor. The blades of the retractor may obscure an injury to the artery with subsequent bleeding.
- Failure to approximate the divided muscles in layers may result in functional and aesthetic problems.

• Clamshell Incision

- Always identify and ligate all four ends of the two divided internal mammary arteries.
- Approximate the divided muscles in layers for best functional and aesthetic results.

• Posterolateral Thoracotomy

- The incision is too low or too high, resulting in poor exposure.
- Making the skin incision over the scapula results in poor aesthetic results. The incision should be 1–2 fingerbreadths below the tip of the scapula.
- Failure to approximate the divided muscles in layers may result in functional and aesthetic problems.

Cardiac Injuries

Demetrios Demetriades, Zachary D. Warriner, and Scott Zakaluzny

Surgical Anatomy

- The pericardium envelops the heart and attaches to the roots of the great vessels. This includes the ascending aorta, pulmonary artery, pulmonary veins, the last 2–4 cm of superior vena cava, and inferior vena cava.
- The phrenic nerves descend on the lateral surfaces of the pericardium.
- Acute accumulation of as little as 200 mL of fluid in the pericardial sac may result in fatal cardiac tamponade.
- The right atrium is paper thin, approximately 2 mm. The left atrium is slightly thicker at approximately 3 mm.
- The right ventricle is approximately 4 mm thick and the left ventricular wall thickness is approximately 12 mm.
- The two main coronary arteries, left main and right coronary arteries, originate at the root of the aorta, as it exits the left ventricle. The left main coronary artery divides into the left anterior descending artery (LAD) and the circumflex artery, and provides blood supply to the left heart. The right coronary artery divides into the right posterior descending and acute marginal arteries, supplying blood to the right heart, as well as the sinoatrial and atrioventricular nodes responsible for regulating cardiac rhythm.

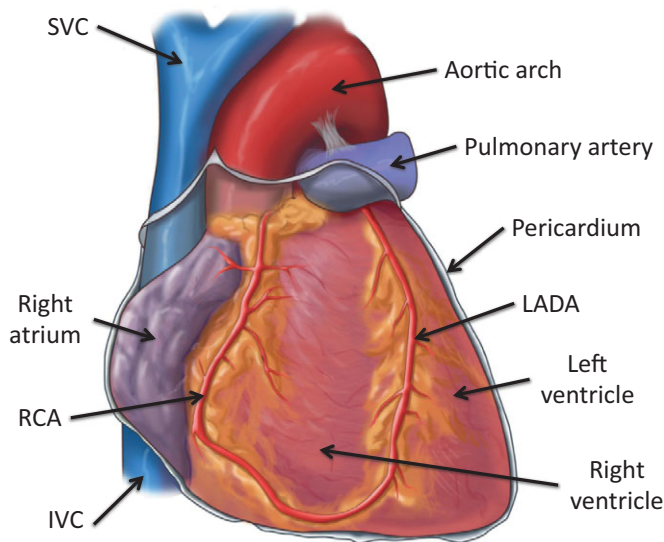


Figure 15.1 Surface anatomy of the heart and great vessels. Note the attachment of the pericardium to the roots of the major vessels. IVC, inferior vena cava; LADA, left anterior descending artery; RCA, right coronary artery; SVC, superior vena cava.

General Principles

- Cardiac injuries are highly lethal and most victims die at the scene. In those who survive to the emergency department, immediate diagnosis and surgical intervention remain the cornerstones of survival. The diagnosis is based on clinical examination and the FAST (Focused Assessment Sonography for Trauma) exam. There is no role for diagnostic pericardiocentesis in a hospital environment, and those with questionable injuries should undergo formal echocardiogram.

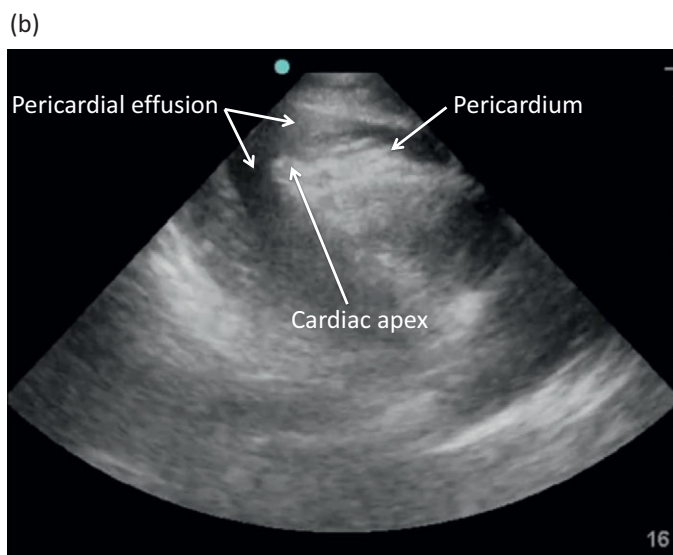
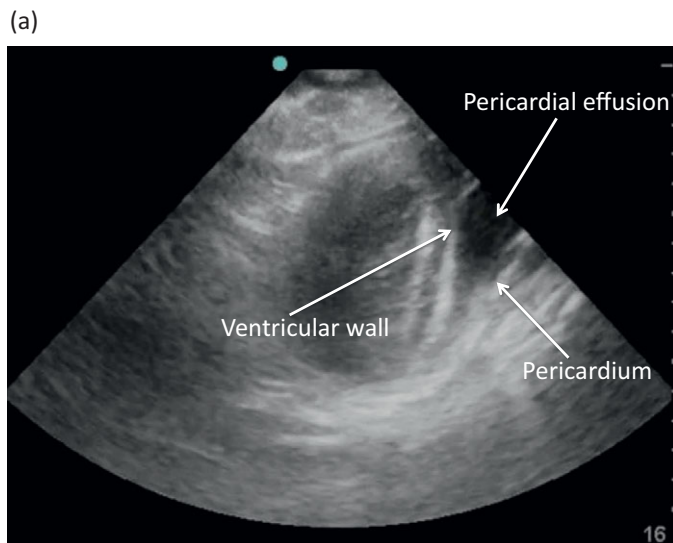


Figure 15.2 (a, b) Subxiphoid cardiac view obtained via FAST (Focused Assessment with Sonography for Trauma) exam demonstrating cardiac tamponade. Hypoechoic hemopericardium is visualized between the myocardium and pericardium.

- Most patients with cardiac injuries have no signs of life or present with severe hypotension on arrival. If there is a short prehospital time or small cardiac injury, the patient may arrive with normal initial vital signs.
- The majority of cardiac injuries are due to penetrating trauma from stab wounds or gunshot wounds. Stab wounds usually involve the right ventricle and gunshot wounds often damage multiple chambers or internal cardiac structures. Cardiac rupture due to blunt trauma is usually fatal and the victims die before reaching medical care. Blunt injuries are predominantly right-sided.
- Patients with no vital signs or imminent cardiac arrest on arrival should be managed with a resuscitative emergency room thoracotomy (see [Chapter 4](#) Emergency Room Resuscitative Thoracotomy).
- Cardiac bypass is almost never required during the initial operation for cardiac repair. The use of temporary intra-aortic balloon pump augmentation or ECMO may be considered in ongoing cardiogenic shock.
- Injuries to the low-pressure cardiac chambers may be complicated by air embolism. Look for air bubbles in the coronary veins. If seen, place the patient in Trendelenburg position and aspirate the right ventricle.

Special Surgical Instruments

- The emergency room thoracotomy tray should be kept simple, with only the absolutely necessary instruments (scalpel, Finochietto retractor, two Duval lung forceps, two vascular clamps, one long Russian forceps, four hemostats, one bone cutter, one pair of long scissors, one pair of suture scissors). In addition, good lighting, working suction, and an internal defibrillator should be immediately available.
- In the operating room, the thoracotomy trauma tray should include a power sternal saw, Lebsche knife with hammer, and bone cutter. The surgeon and skilled assistant should wear a headlamp for optimal lighting in anatomically difficult areas.

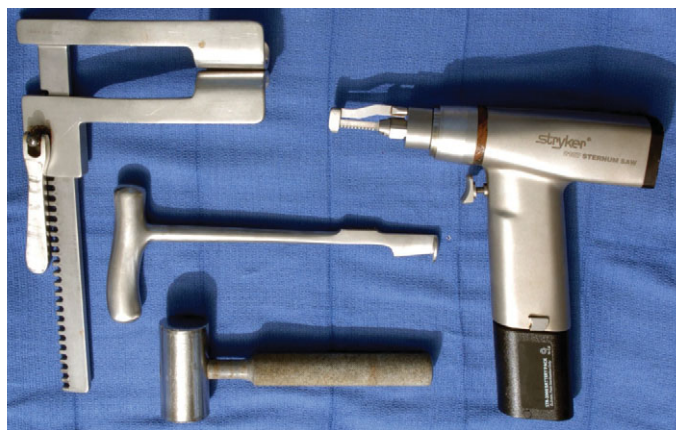


Figure 15.3 Instruments required for median sternotomy: sternal power saw, Lebsche knife, hammer, Finochietto retractor.

Patient Positioning

- For an emergency room left thoracotomy, the patient remains supine on the gurney, with the left arm abducted or elevated above the head. Antiseptic solution is applied on the skin over the anterior chest and bilateral hemithoraces. There is no time for draping or meticulous antiseptic precautions.
- In the operating room, the patient is placed in the supine position with both arms abducted at 90° to allow anesthesia access to the extremities. The left arm may be elevated further above the head if a left anterolateral thoracotomy is to be performed. The skin preparation and draping should include the anterior chest and both hemithoraces. The abdomen should be included if there are suspected associated intra-abdominal injuries.

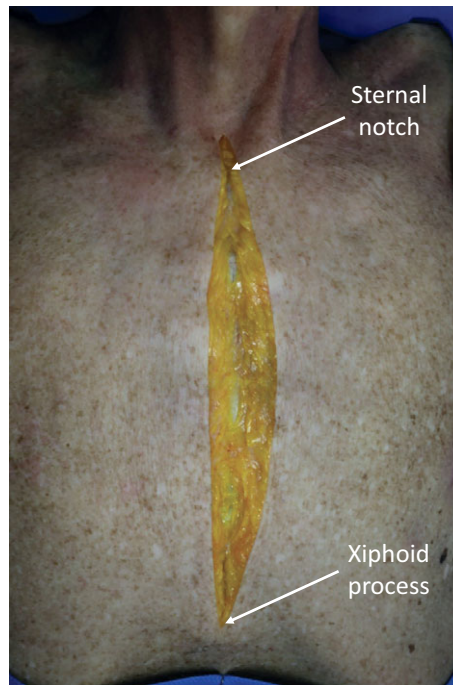
Incisions

- The choice of incision depends on the clinical condition of the patient, the location of the operation (emergency room or operating room), the need for thoracic aortic cross-clamping, and the suspected anatomical site of cardiac injury.
- Patients transported to the emergency room with no vital signs or in imminent cardiac arrest should undergo an immediate left anterolateral thoracotomy on the gurney. This incision is fast, does not need power instruments, and allows cross-clamping of the thoracic aorta for resuscitation purposes (see [Chapter 4](#)).
- In most patients undergoing operation in the operating room, a median sternotomy is the incision of choice. It provides good exposure to the heart and both lungs, it is relatively bloodless, and is associated with less postoperative pain and fewer complications. However, the exposure of the posterior heart or cross-clamping of the aorta may be difficult.
- A left thoracotomy in the operating room is preferable to sternotomy in patients who might need cross-clamping of the aorta or in suspected cases of injury to the posterior wall of the heart.
- Extension of the left thoracotomy into the right chest to create a clamshell incision may be required in patients with bilateral chest trauma (see [Chapter 14](#)), or if exposure of the mediastinal vessels from the left chest alone is inadequate.

Median Sternotomy Incision

- The incision is made over the center of the sternum, extending from the suprasternal notch to the xiphoid. The incision is carried through the sternocostal radiate ligaments, down to the sternum. The interclavicular ligament, at the suprasternal notch, is cleared from its attachment to the sternum using a combination of cautery and blunt dissection with a right angle. Confirm the clearance of the posterior wall of the suprasternal notch by passing the index finger behind the manubrium. The pneumatic saw does not work unless engaged directly with bone. Score the sternum in the midline with scalpel or

(a)



(b)

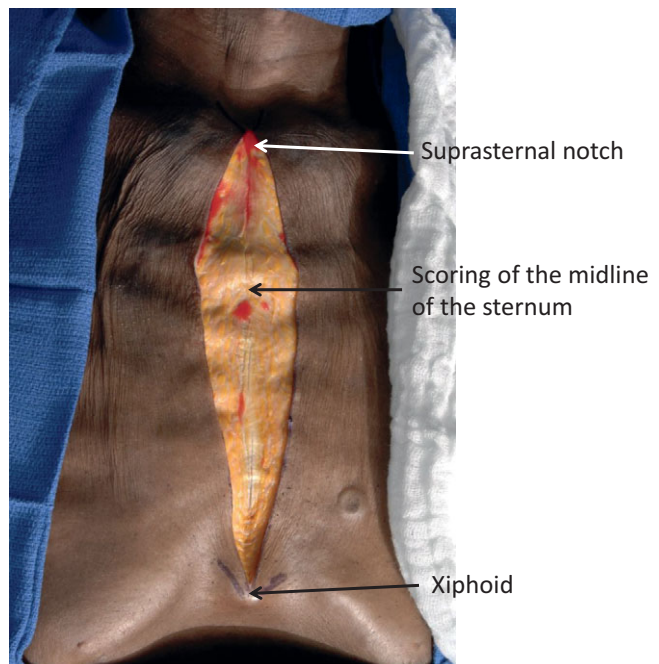


Figure 15.4 (a) Median sternotomy incision extends from the suprasternal notch superiorly to the xiphoid process inferiorly, and is carried down to the sternum. (b) The sternum is scored in the midline to guide the sternal saw.

electrocautery to direct the saw or the Lebsche knife; stay in the middle during the sternal division.

- Place the hook of the pneumatic saw or the Lebsche knife under the suprasternal notch and lift upward on the sternum. Ask anesthesia to hold ventilation temporarily in the expiratory phase and divide the sternum, maintaining upward traction and always remaining in the midline

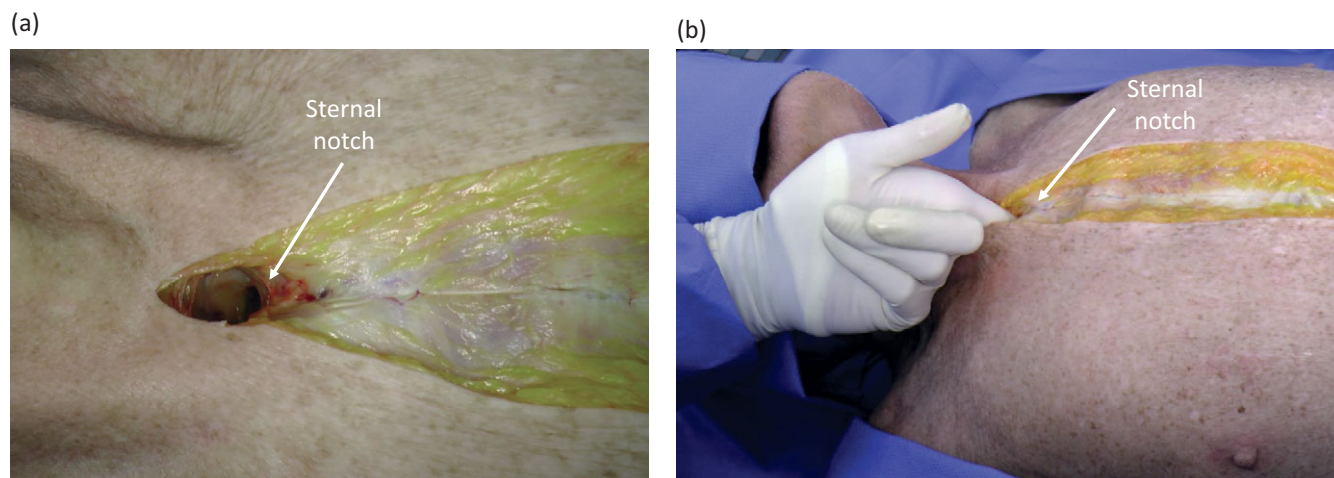


Figure 15.5 The interclavicular ligament is divided (a), allowing palpation of the posterior surface of the sternum with a finger to confirm that soft tissues have been dissected free prior to division of the sternum (b).

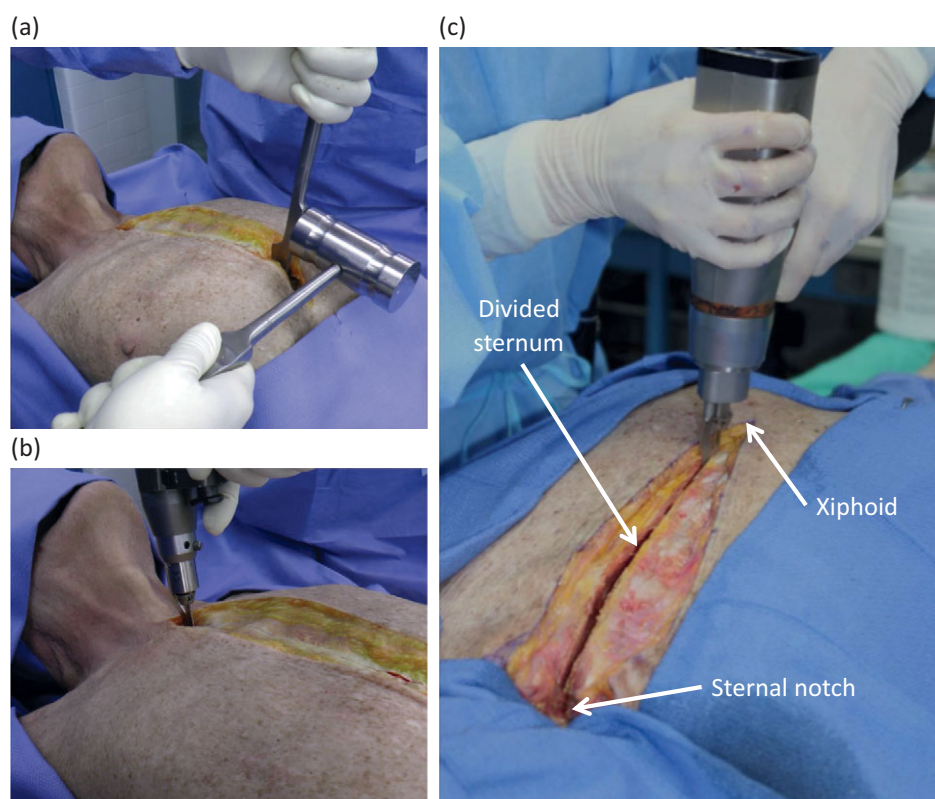


Figure 15.6 The hook of the Lebsche knife (a) or sternal saw (b) is then placed under the sternum and lifted slightly upward. The sternum is divided with constant upward traction, always keeping in the scored midline (c).

- Place the Finochietto retractor in the upper part of the sternum and spread open. The transverse portion of the retractor should be placed cephalad if exploratory

laparotomy is anticipated, or caudad if the neck may be involved. The anterior pericardium is now exposed.

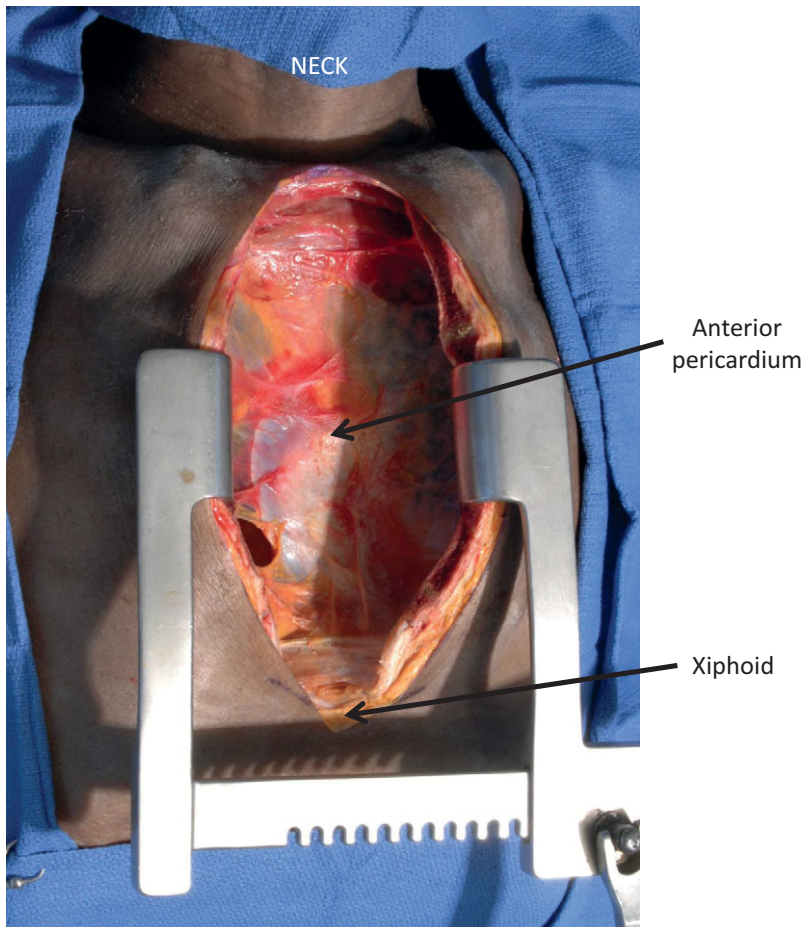


Figure 15.7 The sternum is spread open with a Finochietto retractor and the pericardium is exposed.

Left Thoracotomy Incision

- The incision is made through the left fourth to fifth intercostal space (below the nipple in males, inframammary fold in females), starting from the left parasternal border and extending to the posterior axillary line. Follow the curve of the ribs by aiming towards the axilla (see [Chapter 14](#), [Figures 14.10 a-d](#)).
- The pectoralis major and pectoralis minor are encountered and divided in the anterior part of the incision. The serratus anterior muscle is encountered and divided in the posterior part of the incision (see [Chapter 14](#)).
- The intercostal muscles are then divided close to the superior border of the rib in order to avoid the neurovascular bundle at the inferior aspect. The pleural cavity is entered with the use of scissors, taking precautions to avoid injury to the underlying inflated lung (see [Chapter 14](#)).
- Right-stem intubation or withholding ventilation during entry into the pleural cavity reduces the risk of iatrogenic lung injury.
- A Finochietto retractor is then applied with the transverse portion positioned inferiorly in anticipation of possible

conversion to clamshell incision and the ribs are spread (see [Chapter 14](#)).

Tips and Pitfalls

- During sternotomy, failure to divide the interclavicular ligament and clear the sternum at the suprasternal notch will delay chest entry. The sternum must be devoid of overlying soft tissue to allow appropriate function of the pneumatic saw.
- The median sternotomy may inadvertently go off midline, through the costal cartilages. To avoid this problem, score the sternum in the midline with electrocautery to direct the saw or the Lebsche knife and stay in the middle.
- Placement of the Finochietto retractor in the lower part of the sternum may cause transverse fracture of the sternum. The retractor should be placed in the upper part, where the sternum is thicker and stronger.
- During left thoracotomy: (a) The incision is made too low. This risks injury to an elevated diaphragm and poor exposure of the upper part of the heart. Do not go below the fourth to fifth intercostal space. (b) The incision does not follow the intercostal space, making entry into the chest difficult. The incision should curve with a direction

towards the axilla (see [Chapter 4](#), Emergency Room Resuscitative Thoracotomy).

- Failure to inspect for injury to the left internal mammary artery after removal of the retractor can miss an injury to the artery and severe bleeding. The blades of the retractor may obscure any injury to the artery and result in subsequent bleeding after removal.

Pericardiotomy

- In the absence of tense cardiac tamponade, the pericardium is grasped in the midline with two hemostats or pickups and a small pericardiotomy incision is made.

- In the presence of a tense tamponade, it is difficult to apply the hemostats on the pericardium. In these cases, a small pericardiotomy is performed with a scalpel and the pericardium is then opened longitudinally with scissors.
- If a median sternotomy is performed, the pericardiotomy is performed in the midline.
- With a left thoracotomy, the left phrenic nerve is seen along the lateral surface of the pericardium and the pericardiotomy is performed anteriorly and parallel to the phrenic nerve, delivering the heart for evaluation and potential repair.

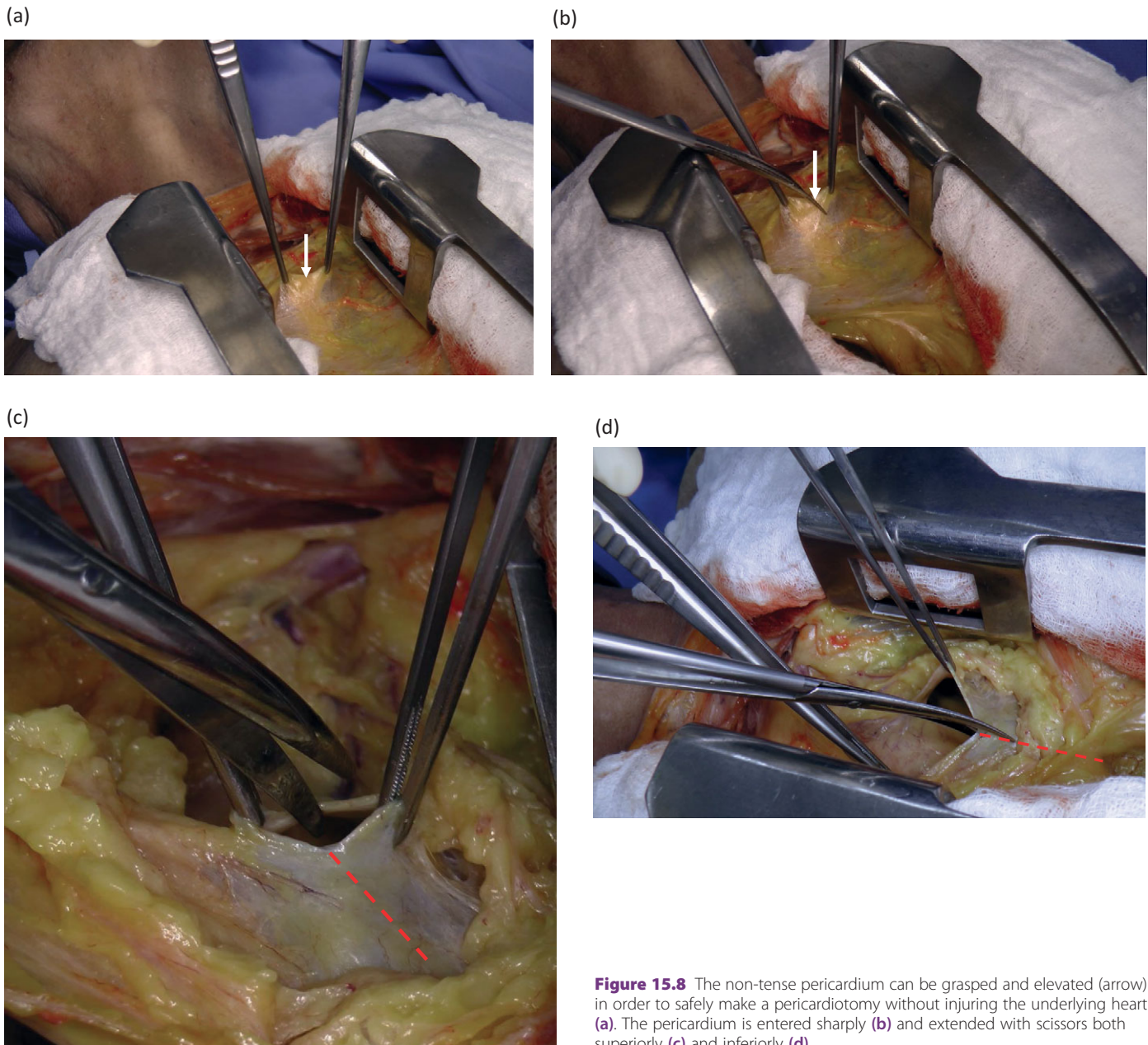


Figure 15.8 The non-tense pericardium can be grasped and elevated (arrow) in order to safely make a pericardiotomy without injuring the underlying heart (a). The pericardium is entered sharply (b) and extended with scissors both superiorly (c) and inferiorly (d).

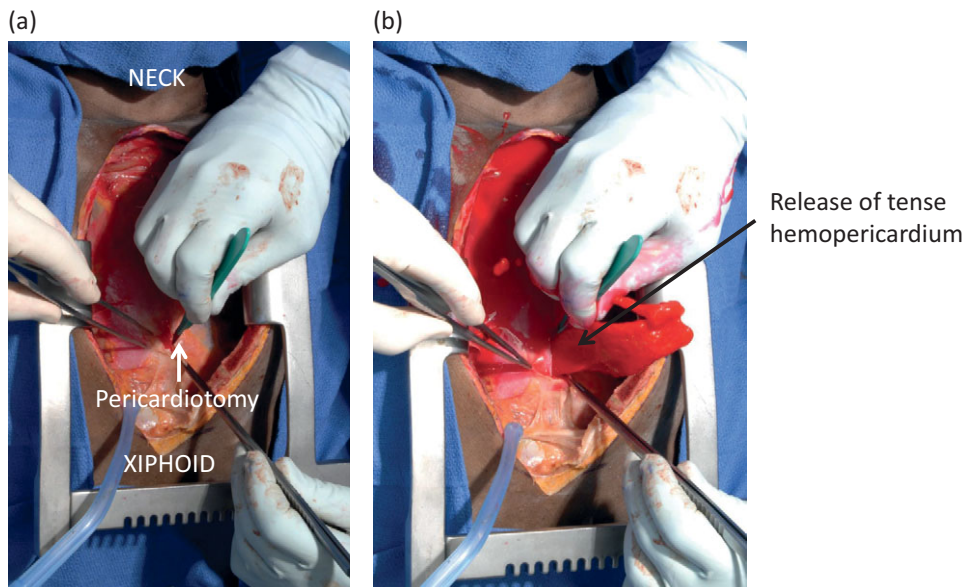


Figure 15.9 In the presence of tense cardiac tamponade, the pericardium is difficult to elevate and must be entered with a scalpel (a), releasing the tamponade (b).

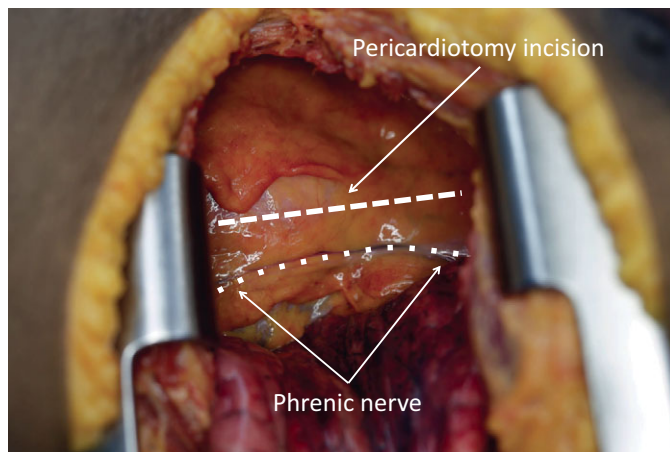


Figure 15.10 When pericardiotomy is made from a left anterolateral thoracotomy incision, care must be taken not to injure the phrenic nerve. The incision is made anterior and parallel to the phrenic nerve, allowing delivery of the heart.

Tips and Pitfalls

- In patients with a tense pericardium, it may be difficult to grasp the pericardium. Make a small pericardiotomy with a scalpel to facilitate entry. Identify and avoid cutting the phrenic nerve.

Bleeding Control and Cardiac Repair

- After the pericardiotomy and release of the tamponade, any direct cardiac bleeding is controlled by finger compression. For larger atrial injuries, a vascular clamp may be used, taking care not to worsen the injury. For

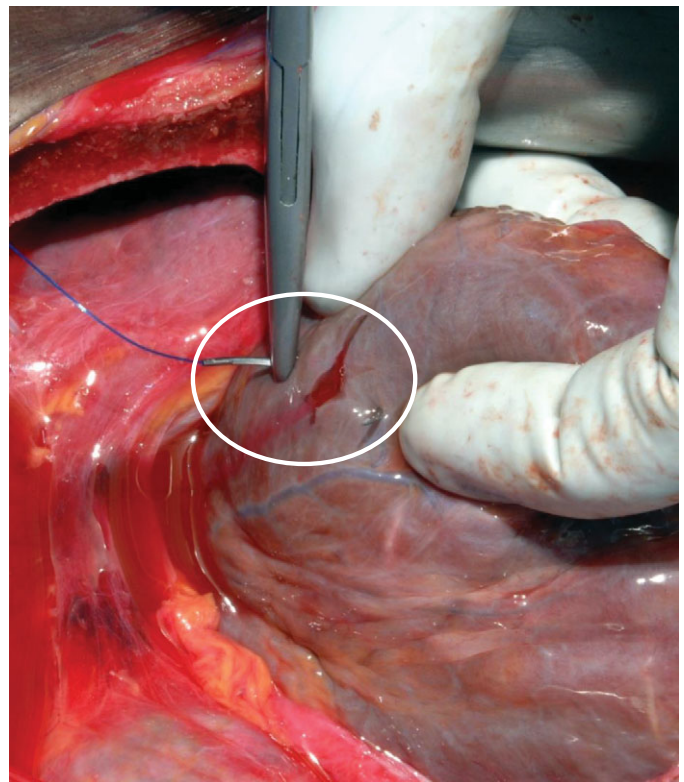
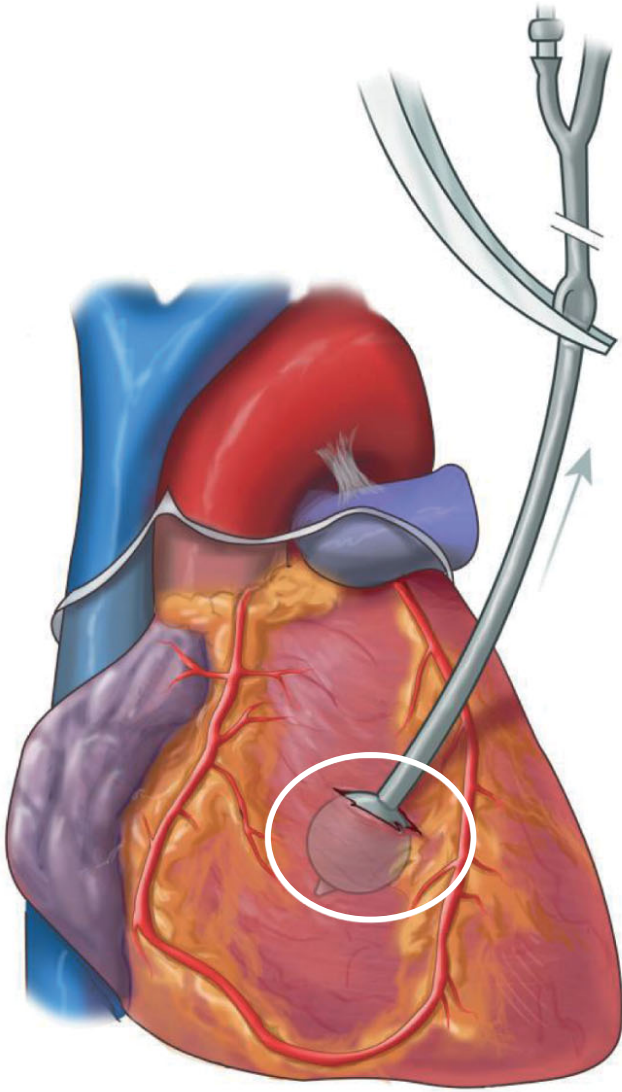


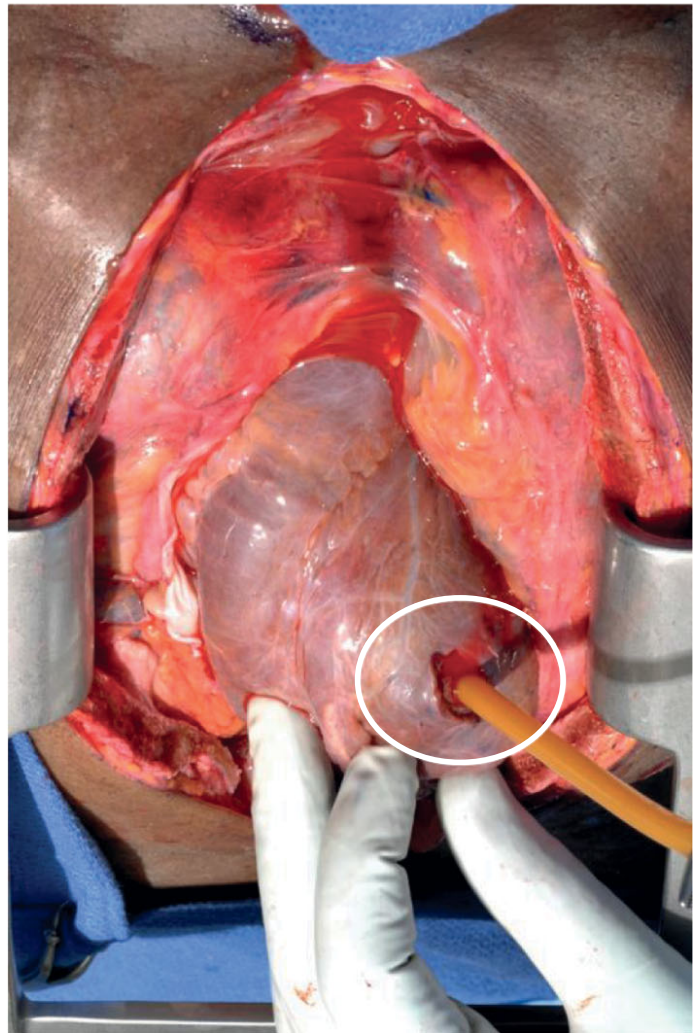
Figure 15.11 Digital compression to initially control bleeding from the cardiac wound to allow suturing.

emergency room thoracotomies, where a small cardiac injury is found, temporary bleeding control may be achieved by inserting and inflating a Foley catheter, followed by application of gentle traction.

(a)



(b)



(c)

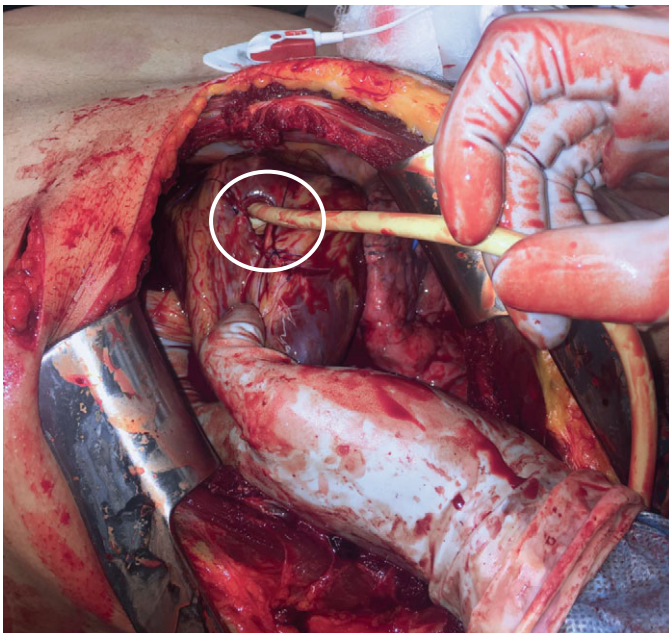
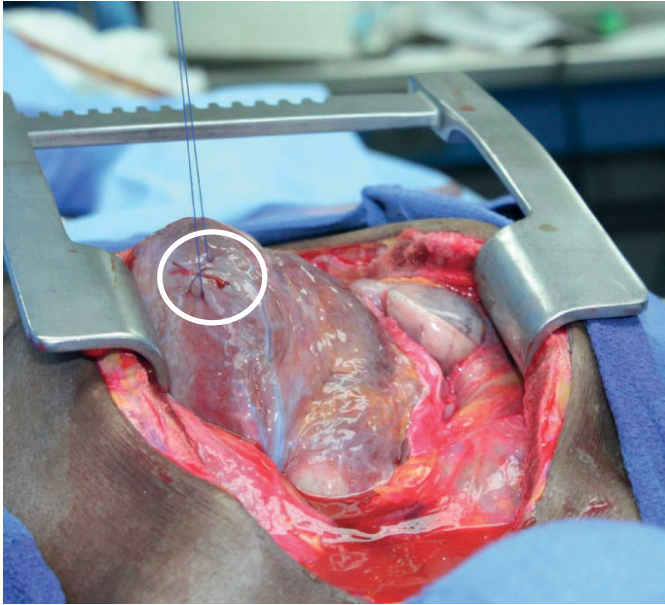


Figure 15.12 A Foley balloon can be used to temporarily control bleeding from a cardiac wound. Exert gentle traction on the catheter to achieve tamponade of the wound. Avoid excessive traction to prevent pulling the balloon through the defect and creating a larger wound (**a, b**). This may be deployed rapidly into difficulty to repair wounds in the emergency department as a temporizing measure to definitive operative repair (**c**).

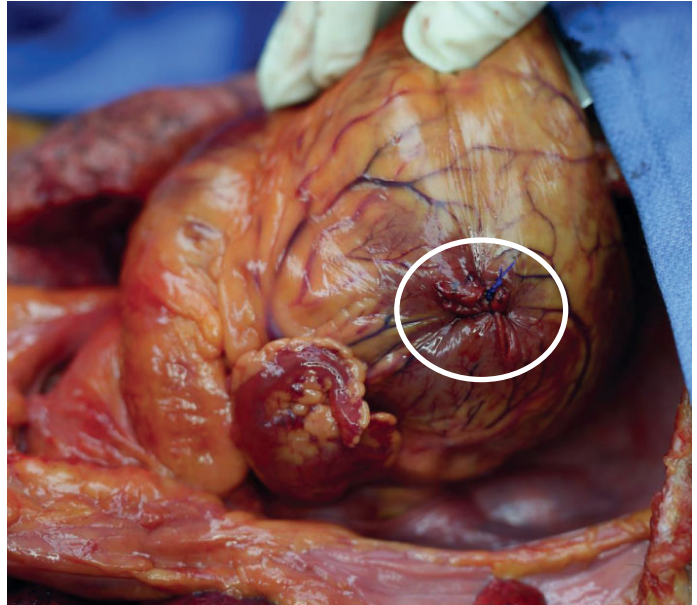
- The cardiac wound is repaired with figure-of-eight, horizontal mattress or running sutures, using nonabsorbable 2-0 or 3-0 suture on a large tapered needle. Routine use of

pledgets is time-consuming and unnecessary in the majority of cases and should be reserved for cases where the myocardium tears during tying of sutures.

(a)



(b)



(c)

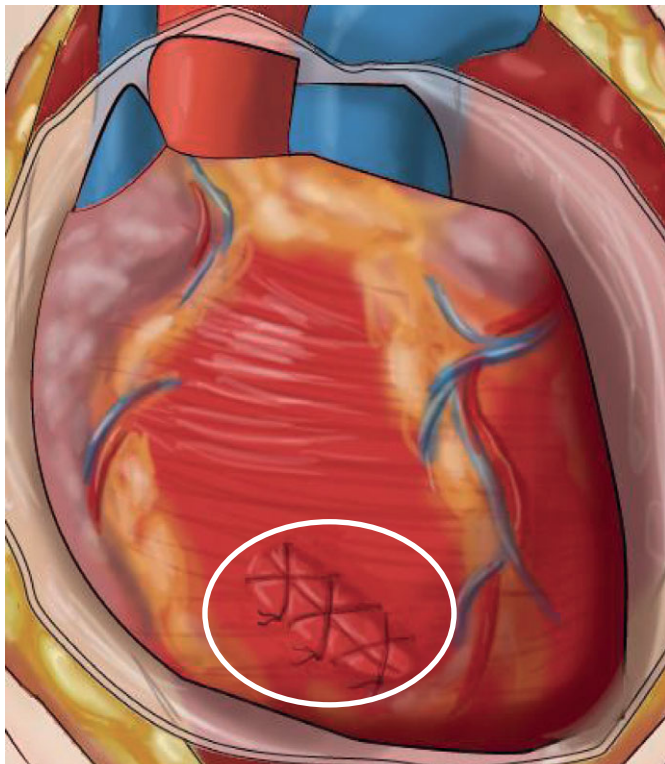


Figure 15.13 (a, b) Most cardiac wounds can be repaired with figure-of-eight sutures of nonabsorbable 2-0 or 3-0 suture on a tapered needle. (c) Repair of a right ventricular wound with figure-of-eight sutures.

- Injuries close to a major coronary vessel should be repaired with horizontal mattress sutures under the vessel to avoid ligation and subsequent myocardial ischemia.

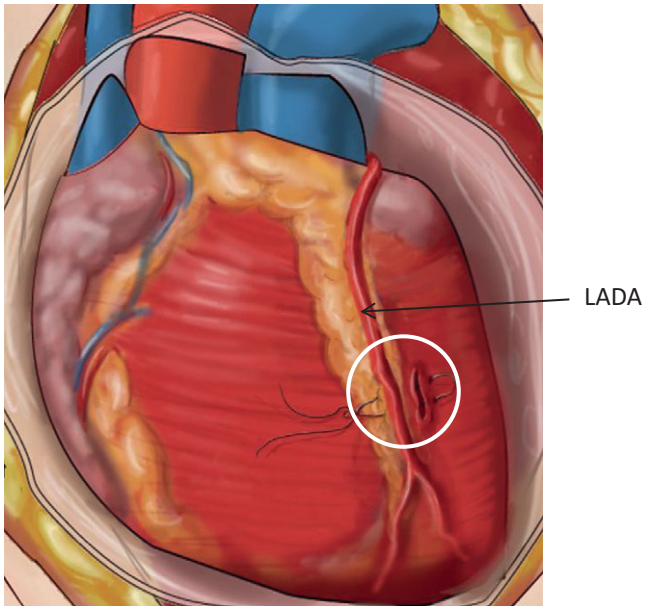


Figure 15.14 Injuries near coronary vessels repaired with a horizontal mattress suture, placed under the vessel.

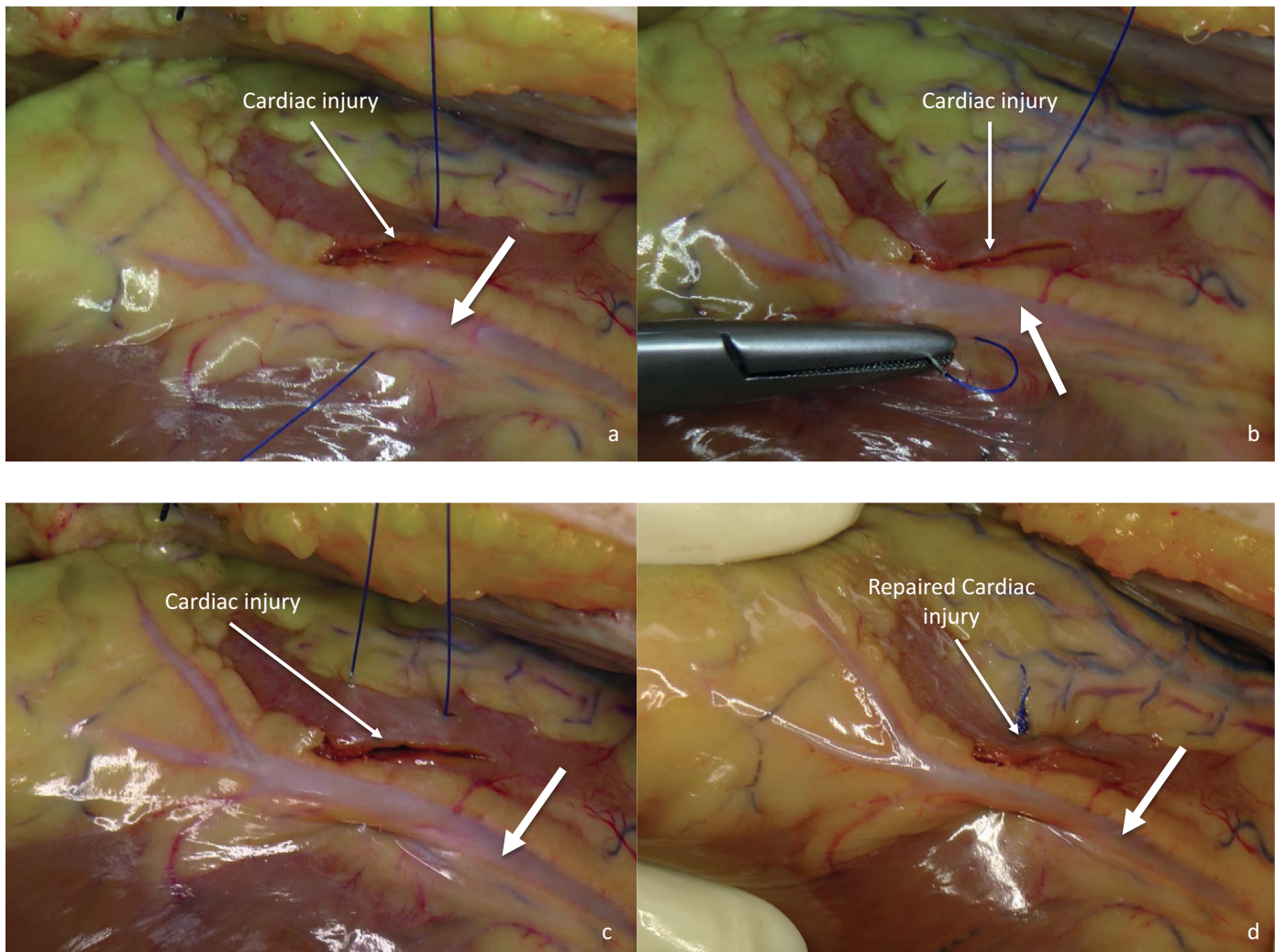


Figure 15.15 (a-d) Stepwise repair of injury adjacent to a coronary vessel (thick white arrows) with horizontal mattress suture placement. Closing defects in this fashion prevents injury, accidental ligation, or stenosis of the adjacent coronary vessel.



Figure 15.16 Cardiac wounds without tissue loss may be closed with staples in the emergency department temporarily. These staples should be replaced by formal suture repair in the operating room.

- Skin staples may be used temporarily for cardiac wound closure in the emergency room, and is primarily effective for stab wounds. This does not work well in patients who have sustained gunshot wounds associated with cardiac tissue loss. The staples should be replaced by sutures in the operating room.
- Partial transection of a major coronary artery can be repaired with interrupted sutures under magnification, while the heart is beating. If this is not technically possible, ligation is performed and the cardiac activity is observed. Distal injuries are usually tolerated well. If no arrhythmia develops, then nothing further is required. If arrhythmia occurs, the suture is removed and gentle finger pressure is applied, while a cardiac team with cardiopulmonary bypass capabilities is mobilized.
- Cardiopulmonary bypass is largely unnecessary during the acute operation. The surgical goal is to save the patient's

life. Any non-life-threatening intracardiac defects should be repaired electively under optimal conditions at a later stage.

- Inspection and repair of injuries to the posterior cardiac wall can be difficult, as lifting of the heart often causes arrhythmia or cardiac arrest. These injuries can be exposed and repaired by grasping the apex of the heart with a Duval clamp and applying mild traction and elevation. Another option is to place a figure-of-eight 2-0 suture on a tapered needle through the apex of the heart for traction and elevation. This option should be performed cautiously because the myocardium may tear during traction. An alternative approach is to slowly elevate the heart by placing sequential laparotomy pads one at a time under the heart to allow adaptation to the change in position. Inflow occlusion of the superior and inferior vena cava, in order to induce cardiac arrest and facilitate repair of the wound, is not advisable, because it is unlikely that the already compromised heart will tolerate normothermic cardiac arrest, even for brief periods of time.

(a)

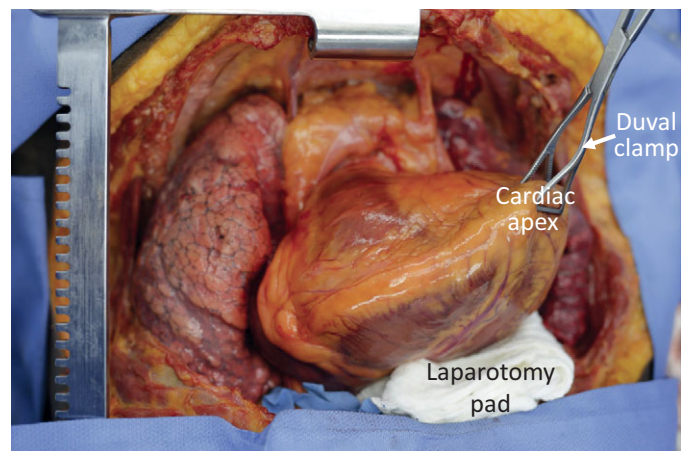
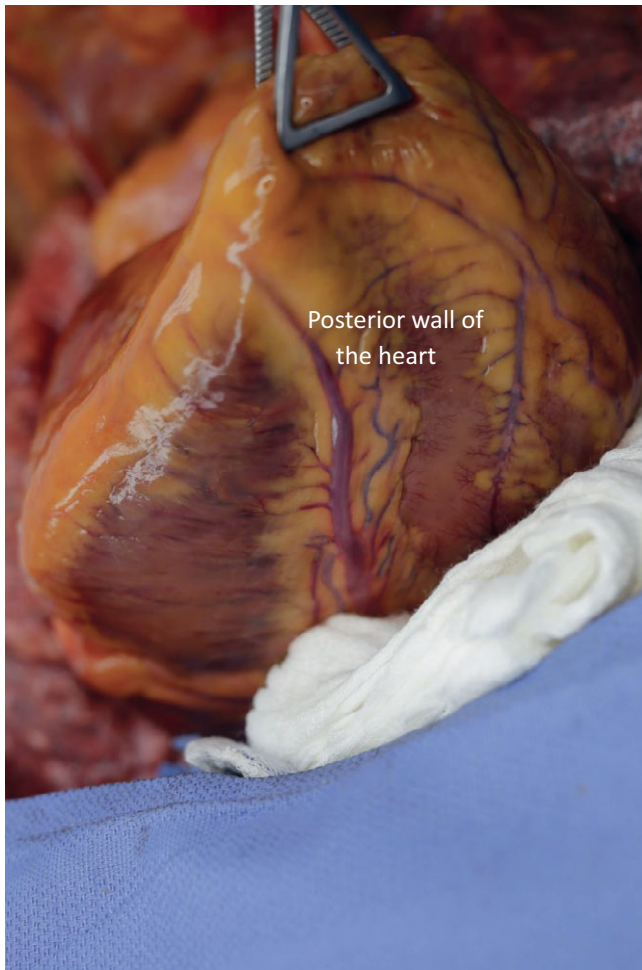
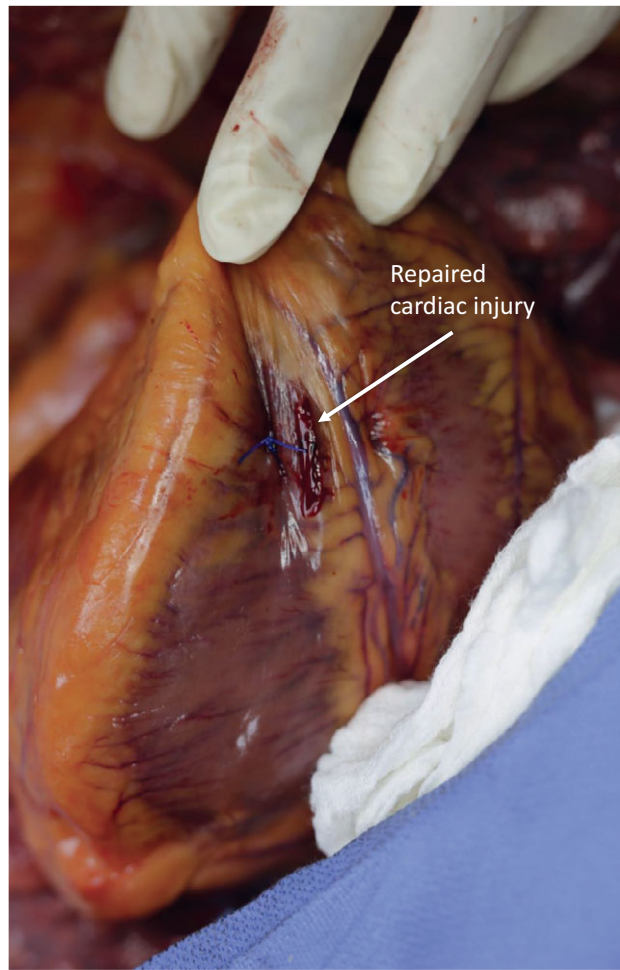


Figure 15.17 The posterior surface of the heart is evaluable by gentle retraction at the apex (a). This position may be achieved or maintained by placing sequential laparotomy pads, one at a time, under the heart (a). This allows appropriate evaluation and repair of injuries in a difficult location (b, c).

(b)



(c)

**Figure 15.17** (cont.)

- In cases of persistent arrhythmias or cardiac arrest, pacing wires should be placed and epicardial pacing initiated (see [Chapter 4](#)).

Pericardial Closure

- Following cardiac repair and stabilization of the patient, the pericardium is closed with continuous 2-0 sutures, leaving an opening near the base of the pericardium to avoid tamponade in case of recurrent bleeding.
- In patients with acute cardiac enlargement due to cardiac failure or massive fluid resuscitation, the pericardium should be left open to prevent arrhythmias.

Technical Pitfalls

- Closure of the pericardium under tension may precipitate an arrhythmia and cardiac arrest.

Closure of Median Sternotomy

- Ensure hemostasis of the sternal edge with cautery or bone wax application.
- Check for bleeding from the internal mammary arteries beneath the sternum after removal of the sternal retractor. This is particularly important with relative hypotension, as vasospasm may resolve, resulting in delayed life-threatening hemorrhage.
- Place at least one water-sealed chest drain under the sternum.
- Close the sternum with steel wires using a heavy needle driver.
- Close the presternal fascia with heavy absorbable sutures.

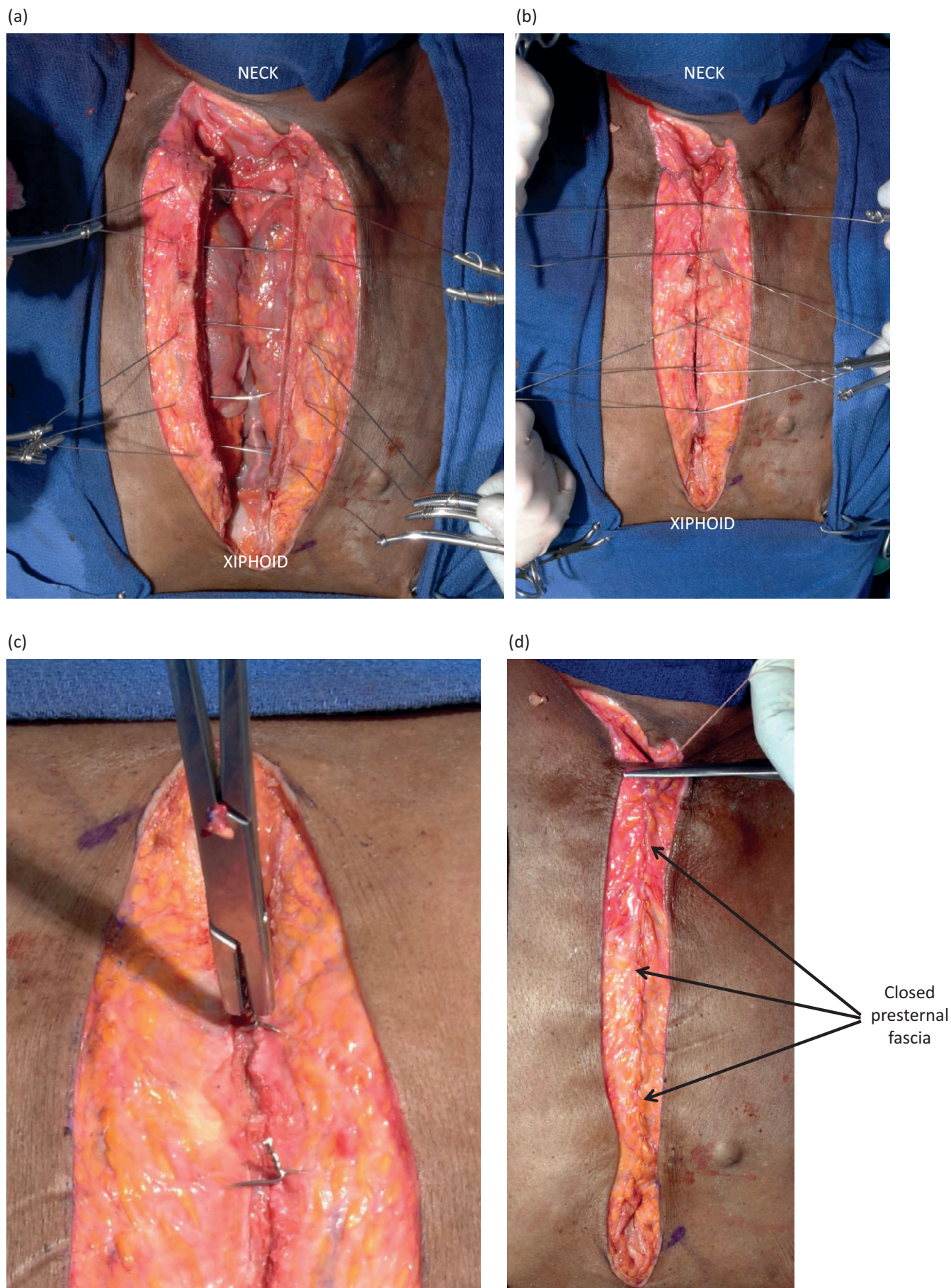


Figure 15.18 (a–c) The sternum is closed with wires. Each should be placed prior to closure, followed by simultaneous tightening of wires to approximate edges of the sternum. The wires are trimmed and undergo final rotation with a heavy needle driver. (d) The presternal fascia is closed with heavy absorbable sutures.

Tips and Pitfalls

- Failure to inspect the integrity of the internal mammary artery after the removal of the sternal retractor can result in significant and persistent postoperative bleeding.

Postoperative Care

- All survivors should undergo routine early and late echocardiographic evaluation to rule out significant intracardiac injuries, which may include septal defects, valvular or papillary muscle dysfunction, myocardial dyskinesia, and late pericardial effusion.
- Emergency resternotomy should be considered in any cardiac arrest after cardiac surgery to evaluate for bleeding or tamponade. Any ICU caring for the post cardiac surgery patient should have this kit readily available.
- Postoperative arrhythmia should be evaluated for possible defibrillation vs. those amenable to pacing, including bradycardia or asystole.

Thoracic Vessels

Demetrios Demetriades, Vincent Chong, and Stephen Varga

Surgical Anatomy

- The upper mediastinum contains the aortic arch with the origins of its major branches. These include the innominate (brachiocephalic) artery, proximal left common carotid artery, and proximal left subclavian artery. The left and right innominate (brachiocephalic) veins join to become the superior vena cava (SVC).
- The thymic remnant and surrounding mediastinal fat are the first tissues encountered when entering the upper mediastinum. These tissues lie over the left innominate vein and the aortic arch.
- The left innominate vein is approximately 6–7 cm long and it transverses the upper mediastinum under the manubrium sterni and over the superior border of the aortic arch. It joins the right innominate vein just to the right of the sternum at the level of the first to second intercostal space to form the SVC.
- The right innominate vein is approximately 3 cm in length and it courses vertically downward and joins the left innominate vein at a 90° angle to form the SVC.
- The SVC is approximately 6–7 cm in length and is located lateral and parallel to the ascending aorta. A small segment is enclosed within the pericardium.
- The ascending aorta is contained within the pericardium. The aortic arch begins at the superior attachment of the pericardium. The first branch of the aortic arch is the innominate artery, which then branches into the right subclavian and right common carotid arteries. The next branch of the arch is the left common carotid artery, followed by the left subclavian artery. The innominate artery and the left common carotid artery originate relatively anteriorly, while the left subclavian artery originates more posteriorly. Anatomical variants include a common origin for the left common carotid artery and innominate artery, as well as a common origin for the left subclavian and left common carotid artery.

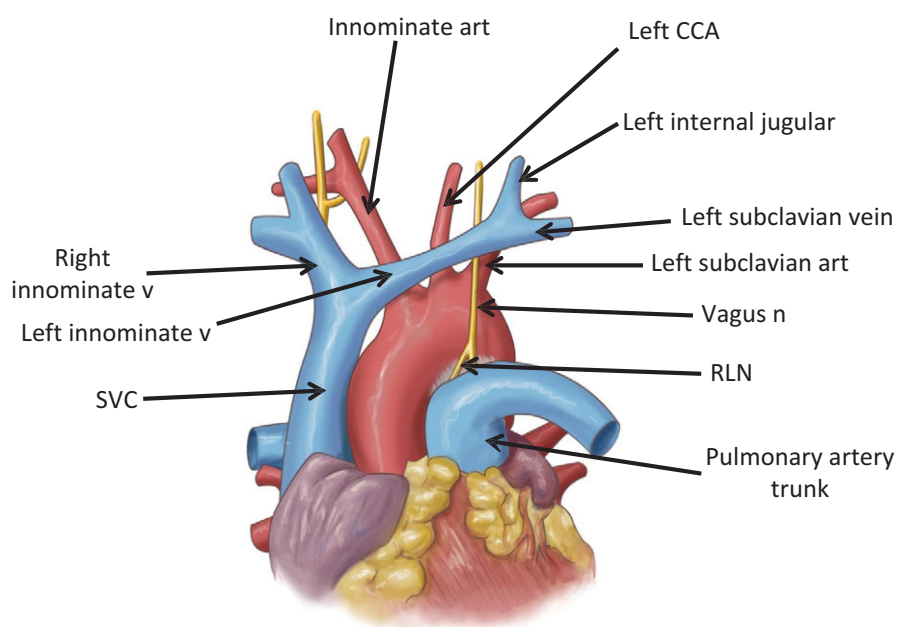


Figure 16.1 Anatomy of the vessels of the superior mediastinum. Note the left innominate vein traversing over the superior border of the aortic arch and its major branches. RLN, recurrent laryngeal nerve; SVC, superior vena cava.

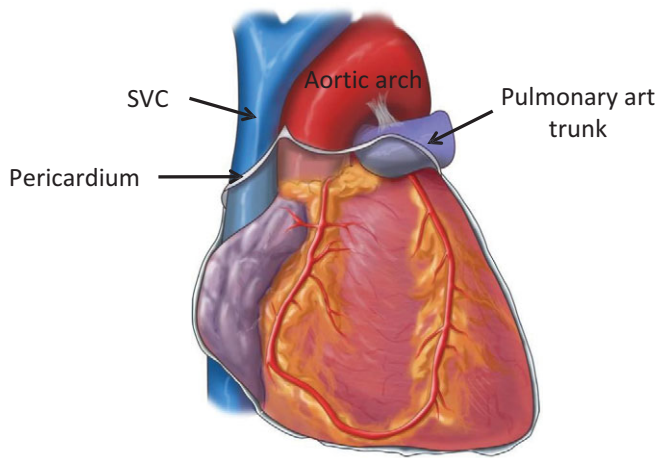


Figure 16.2 The roots of the major vessels (aorta, superior vena cava, and pulmonary trunk) are covered by the pericardium.

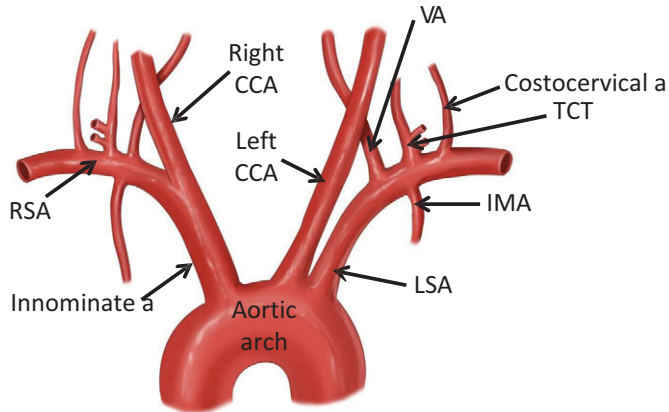


Figure 16.3 The major vessels of the aortic arch (innominate artery, left common carotid, left subclavian artery). The left common carotid originates directly from the aorta, while the right common carotid branches from the innominate artery. CCA, common carotid artery; IMA, internal mammary artery; SCA, subclavian artery; TCT, thyrocervical trunk; VA, vertebral artery.

- The left vagus nerve travels between the left common carotid and subclavian arteries just anterior to the arch and branches off into the recurrent laryngeal nerve, which loops around and behind the aortic arch, ascending along the tracheoesophageal groove.
- The right vagus nerve crosses over the right subclavian artery, immediately gives off the recurrent laryngeal nerve, which loops behind the subclavian artery and ascends behind the common carotid artery along the tracheoesophageal groove.

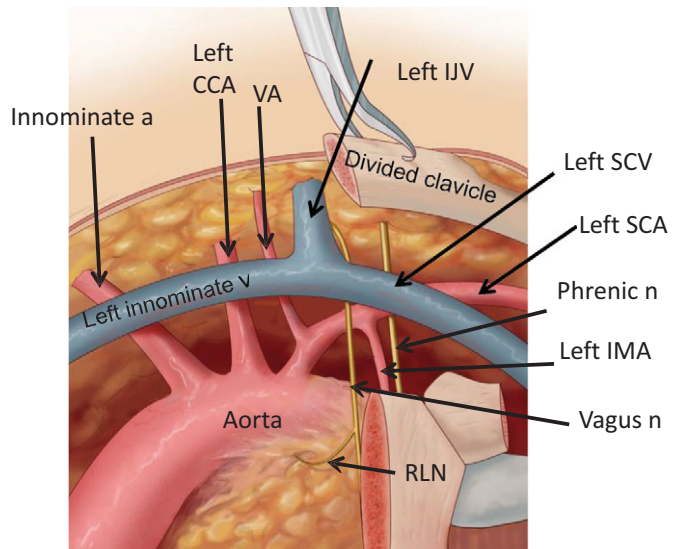


Figure 16.4 Anatomy of the aortic arch and its major trunks; note the anatomical relationship with the left innominate vein, the left vagus and left phrenic nerves. The vagus nerve is medial and the phrenic nerve lateral to the internal mammary artery. CCA, common carotid artery; IMA, internal mammary artery; RLN, recurrent laryngeal nerve; SCA, subclavian artery; SCV, subclavian vein; VA, vertebral artery.

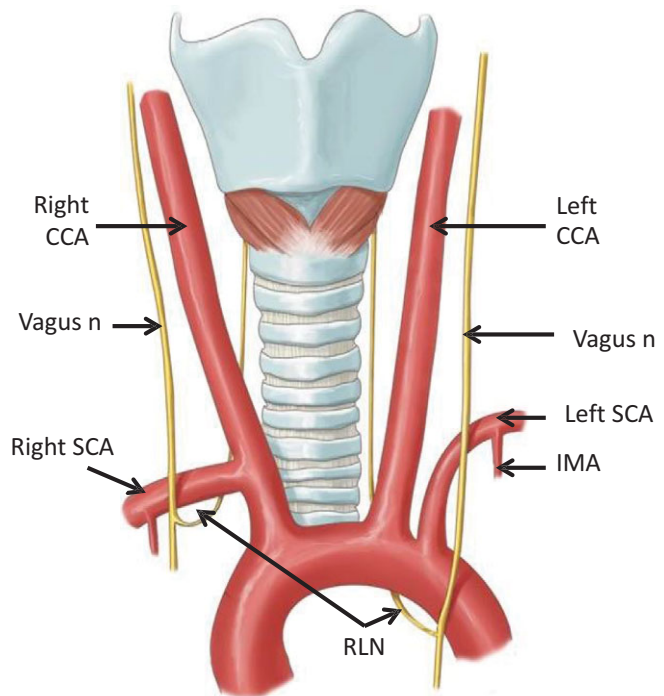


Figure 16.5 Anatomical relationship between the vagus nerve and the major vessels. The nerve crosses in front of the proximal subclavian artery. The recurrent laryngeal nerve loops around the subclavian on the right side and around the aortic arch on the left side. CCA, common carotid artery; IMA, internal mammary artery; RLN, recurrent laryngeal nerve; SCA, subclavian artery.

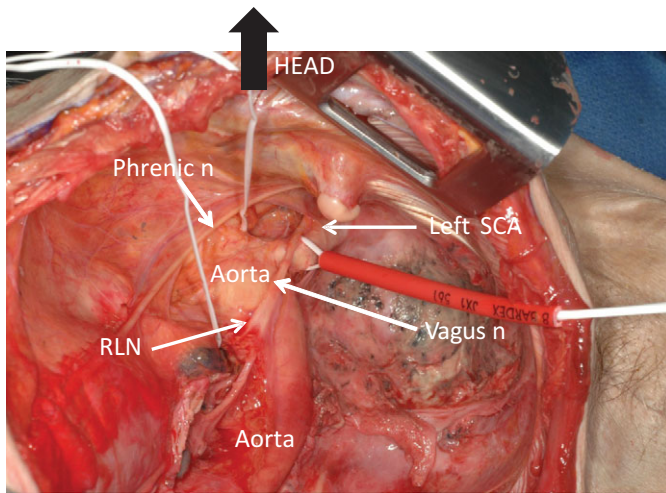


Figure 16.6 The left vagus nerve crosses over the proximal left subclavian artery and the aortic arch. At the inferior border of the arch it gives the left recurrent laryngeal nerve. SCA, subclavian artery.

- The thoracic or descending aorta begins at the fourth thoracic vertebra on the left side of the vertebral column. Below the root of the lung, it courses to a position anterior to the vertebral column as it passes into the abdominal cavity through the aortic hiatus in the diaphragm at the twelfth thoracic vertebra.
- The esophagus lies on the right side of the aorta proximally. Distally, as it enters the diaphragm, it courses in front of the aorta.

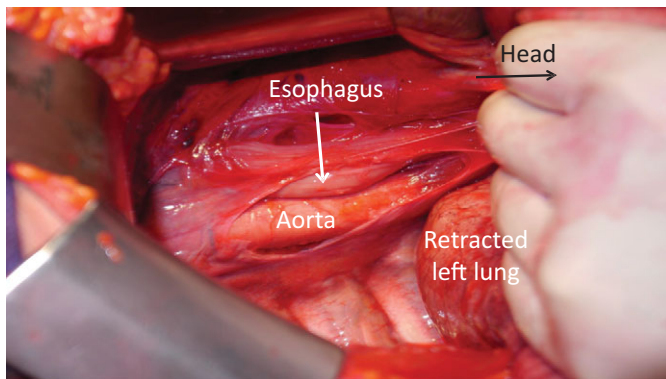


Figure 16.7 Anatomical relationship between the esophagus and the thoracic aorta. The esophagus lies on the right side of the aorta. Just above the diaphragm, it courses in front of the aorta.

- The aorta has nine pairs of aortic intercostal arteries that arise from the posterior aspect of the aorta and travel to the associated intercostal spaces. The bronchial and esophageal arteries are additional branches of the aorta as it descends in the thorax.

General Principles

- Greater than 90% of thoracic great vessel injuries are due to penetrating trauma. Most patients with penetrating trauma

to the major mediastinal vessels die at the scene and never reach hospital care.

- For those that survive to hospital presentation, most patients arrive with hemodynamic instability and require emergency operation without any diagnostic studies.
- Patients with no vital signs or imminent cardiac arrest on arrival should be managed with a resuscitative emergency room thoracotomy (See [Chapter 4](#)).
- In hemodynamically stable patients with suspected injuries to the mediastinal vessels, CT arteriography is the most effective screening diagnostic investigation.
- Thoracic great vessel injuries can present with external or internal hemorrhage, vascular thrombosis from intimal flaps, or pseudoaneurysms. Consequently, the absence of a significant amount of bleeding does not rule out a vascular injury.

Special Surgical Instruments

- In the operating room, the thoracotomy trauma tray should include vascular instruments, a power sternal saw, Lebsche knife with hammer, and bone cutter. The surgeon should wear a headlamp for optimal lighting in anatomically difficult areas.

Patient Positioning

Positioning for Upper Mediastinal Vascular Injuries

- The patient is placed in the supine position with both arms abducted at 90° to allow the anesthetist access to the extremities.
- Skin preparation and draping should include the neck, anterior chest, and hemithoraces. As for all acute trauma operations, the abdomen and groin should be prepared as well in case of an unexpected missile trajectory or the need for saphenous vein conduit.

Positioning for Exposure of the Descending Thoracic Aorta

- Place patient in right lateral decubitus position (See [Chapter 14](#)).
- If possible, use a double-lumen endotracheal tube, and have the left lung deflated once the pleural cavity has been entered.

Incisions

Median Sternotomy

- A median sternotomy provides excellent exposure of the upper mediastinal vessels. In addition, it provides good exposure to the heart and both lungs.
- The median sternotomy incision can also be extended into the neck with a sternocleidomastoid incision. A clavicular extension allows for more distal exposure of the common carotid artery or the subclavian vessels.

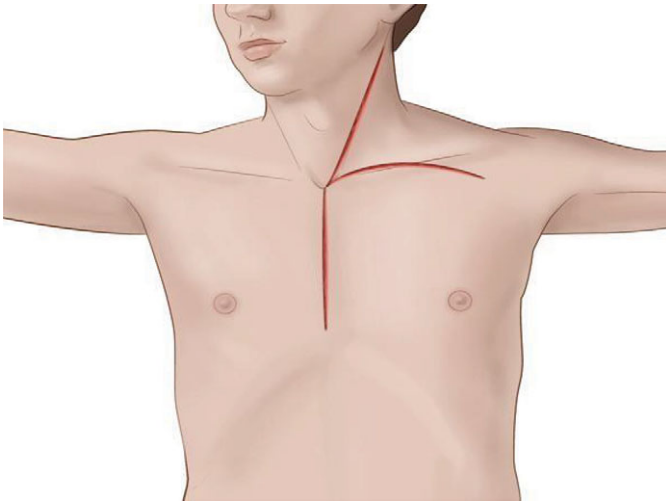


Figure 16.8 The median sternotomy incision may be extended into the neck with a sternocleidomastoid incision for improved exposure of the common carotids or a clavicular incision to allow more distal exposure of the subclavian vessels.

Clamshell Incision

- The clamshell incision provides good exposure of the anterior aspect of the heart, the superior mediastinal vessels, and both lungs. It is usually performed as an extension of a standard anterolateral thoracotomy to the opposite side.
- The incision is made through the fourth to fifth intercostal space bilaterally with transverse division of the sternum, using a Lebsche knife, bone cutter, or heavy scissors.
- During the division of the sternum, both internal mammary arteries are transected. Identification and ligation of the proximal and distal ends should be performed.

(a)

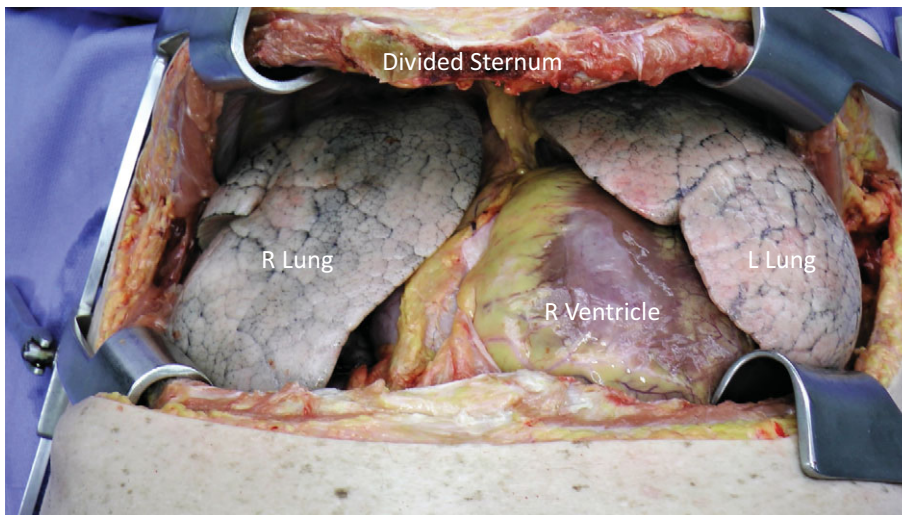
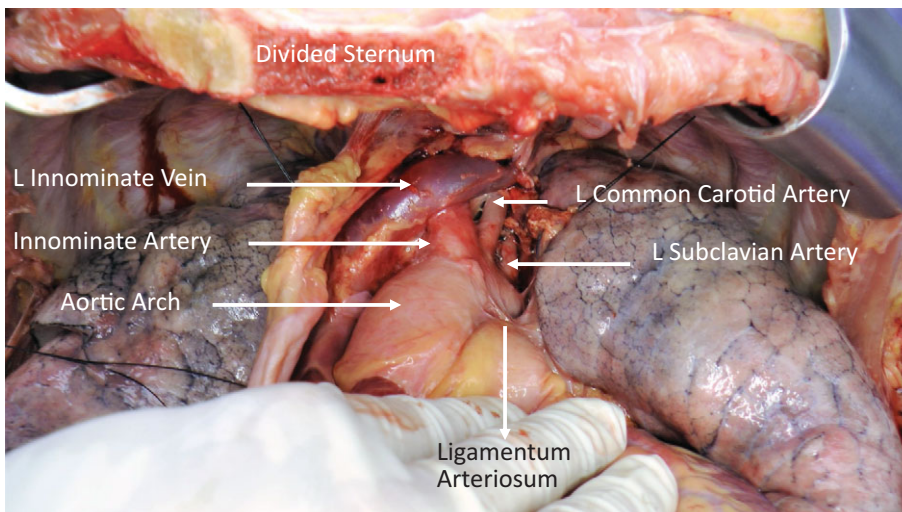


Figure 16.9 (a, b) The clamshell incision is made through the fourth to fifth intercostal space bilaterally with transverse division of the sternum. It provides a good exposure of the anterior aspect of the heart, the superior mediastinal vessels, and both lungs.

(b)



Posterolateral Thoracotomy

- This is the optimal incision for the management of injuries to the descending thoracic aorta. However, in the majority of penetrating trauma cases, due to severe hemodynamic instability, the patient is placed in the supine position and an extended anterolateral incision is performed.
- If possible, use a double-lumen endotracheal tube, and have the left lung deflated once the pleural cavity has been entered.
- Perform a generous left posterolateral thoracotomy in the fourth or fifth intercostal space just below the left nipple all the way up between the scapula and the spine, making sure to divide the latissimus dorsi and the serratus anterior.

Exposures

Exposure of the Upper Mediastinal Vessels

- Following median sternotomy or clamshell incision, the first step is to open the pericardium to rule out injury

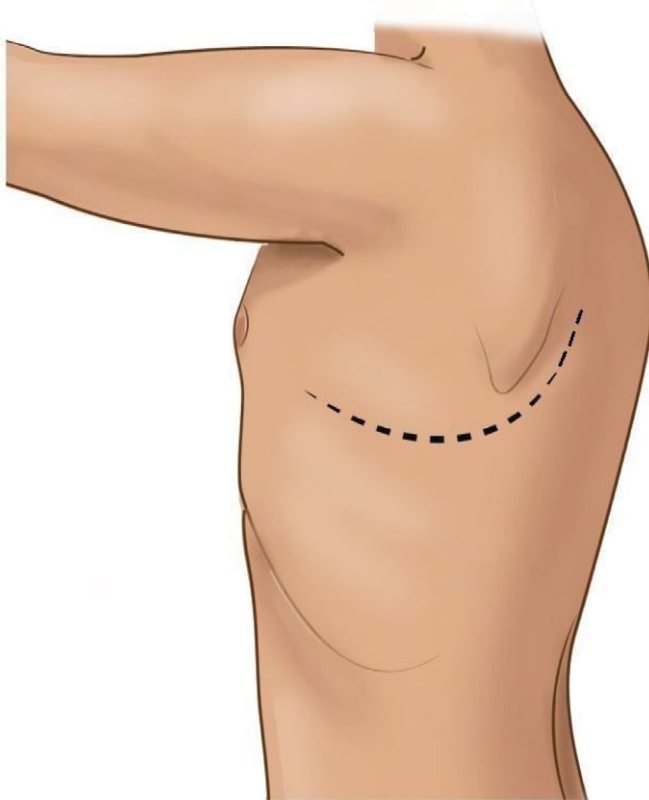


Figure 16.10 Positioning and incision for the exposure of the descending thoracic aorta.

to the heart or the intrapericardial segment of the great vessels.

- All mediastinal hematomas due to penetrating trauma should be explored, if possible after proximal and distal control.
- The first tissues encountered under the sternum in the upper mediastinum are the thymic remnant with surrounding fat pad, which lie directly over the left innominate vein and the aortic arch. These tissues are grasped with an Allis forceps and lifted towards the patient's head. Careful blunt dissection exposes the left innominate vein.
- Vessel loops are placed around the left innominate vein. Dissection of the vessel allows identification of its near perpendicular junction with the right innominate vein, where the SVC begins. The SVC lies parallel and to the right of the ascending aorta.

(a)

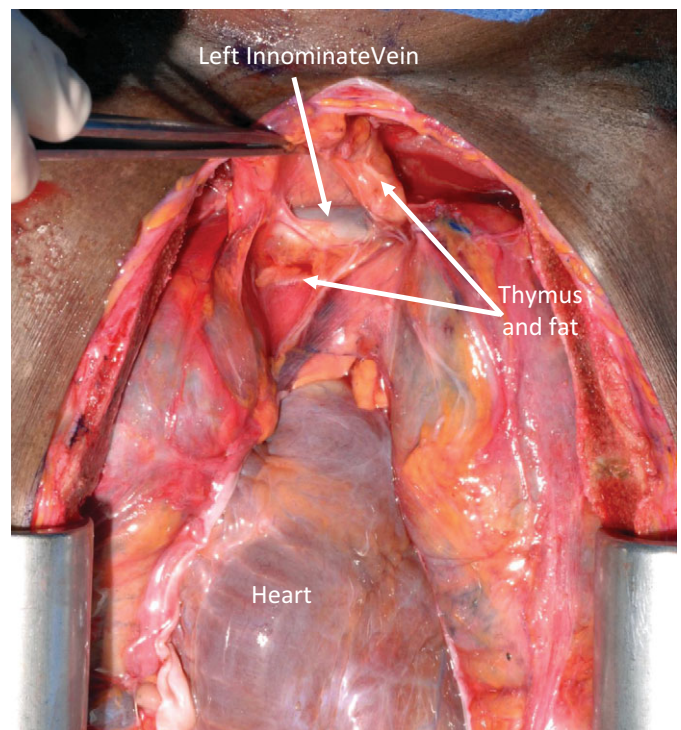


Figure 16.11 (a) Mobilization of the thymus and upper mediastinal fat pad. The first tissues encountered under the sternum in the upper mediastinum are the thymic remnant with the surrounding fat pad, which lie directly over the left innominate vein and the aortic arch. Mobilization of these tissues exposes the left innominate vein. (b) Complete mobilization of the left innominate vein and exposure of the superior vena cava (SVC).

(b)

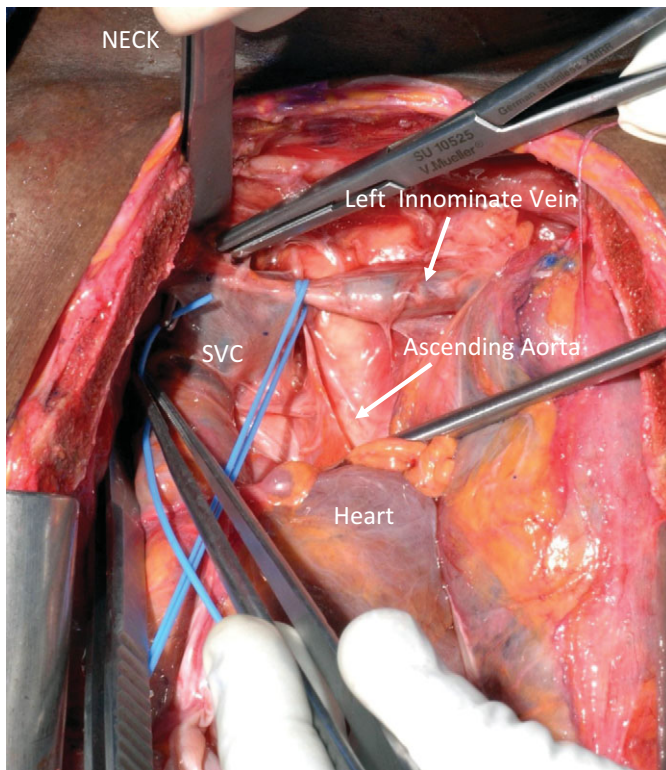
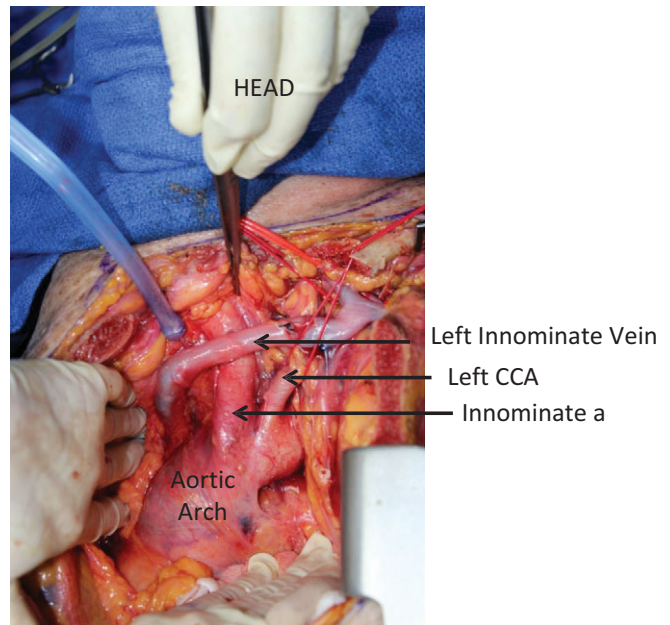


Figure 16.11 (cont.)

- Exposure of the aortic arch and the origins of the major vessels require retraction of the left innominate vein, which lies directly over the upper border of the arch. On rare occasions, the left innominate vein may need to be ligated to provide better exposure of the transverse aorta and its branches.

(a)



(b)

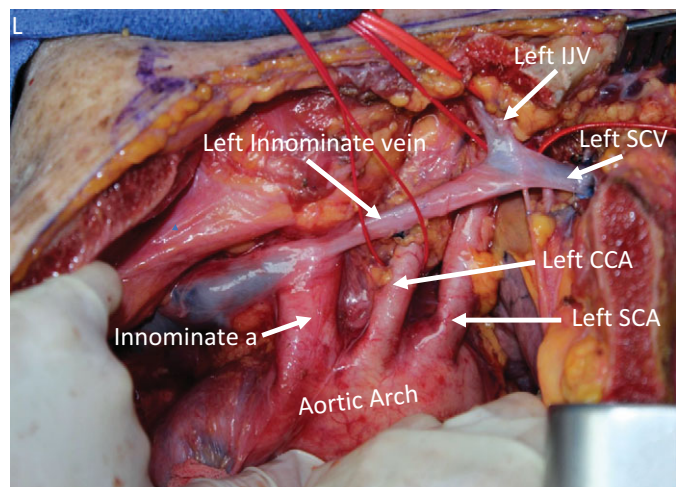


Figure 16.12 The proximal innominate artery and left common carotid artery lie directly under the left innominate vein (a). The left subclavian artery is lateral and more posterior and needs further dissection for exposure (b). CCA, common carotid artery; IJV, internal jugular vein; SCA, subclavian artery; SCV, subclavian vein).

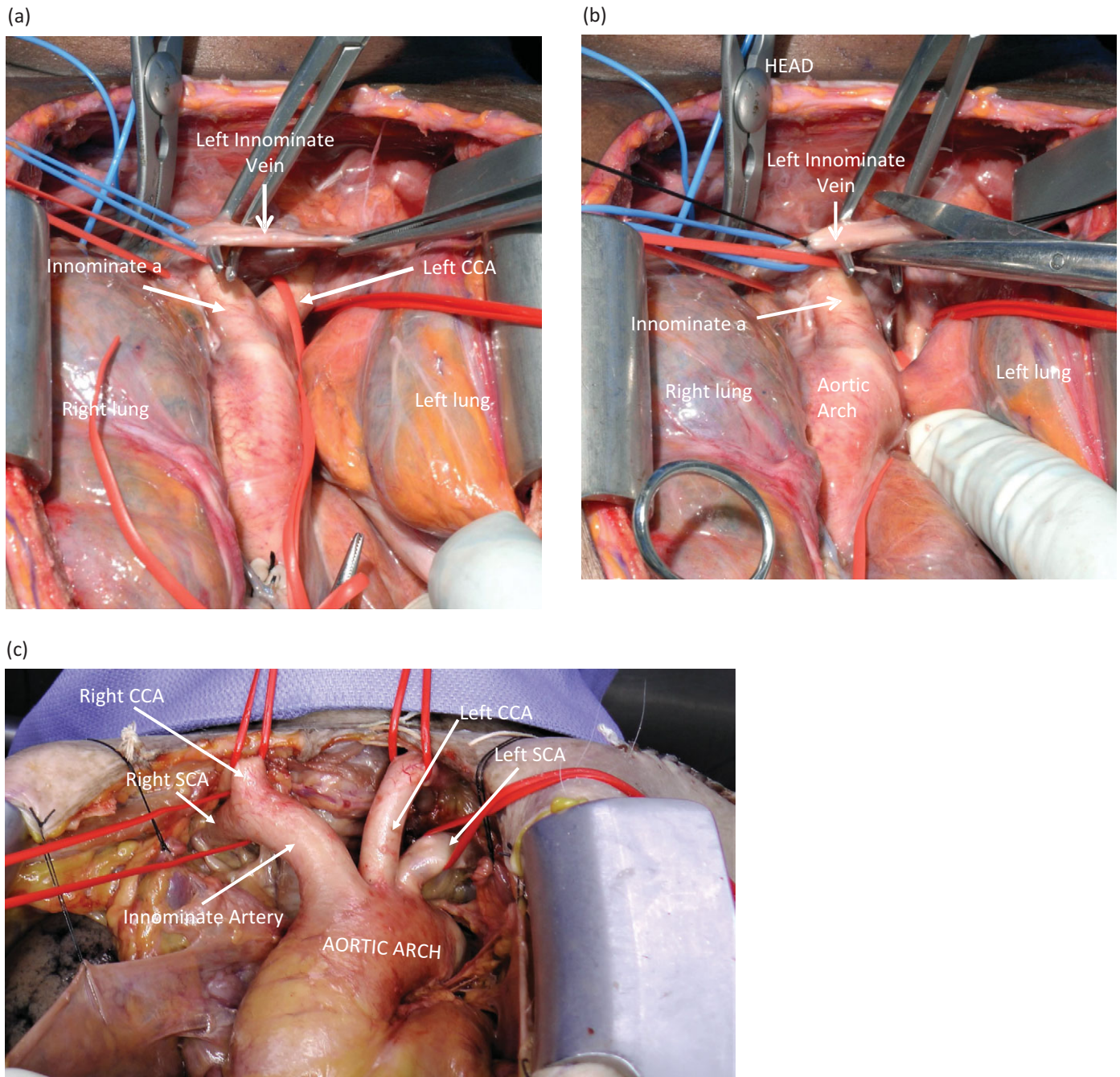


Figure 16.13 (a) The left innominate vein may be ligated and divided to allow for greater exposure to the aortic arch and proximal innominate artery. (b) Dissection and division of the left innominate vein. (c) Improved exposure of the aortic arch and its branches after division of the left innominate vein. CCA, common carotid artery; SCA, subclavian artery.

- The innominate and left carotid arteries originate from the anterosuperior aspect of the aortic arch and are easy to identify and control with vessel loops. However, the left subclavian artery is more posterior and more difficult to isolate.
- Mobilization and isolation of the distal innominate artery may be difficult through a median sternotomy. In these cases, the incision may be extended to the right neck through a standard sternocleidomastoid incision to improve the exposure.

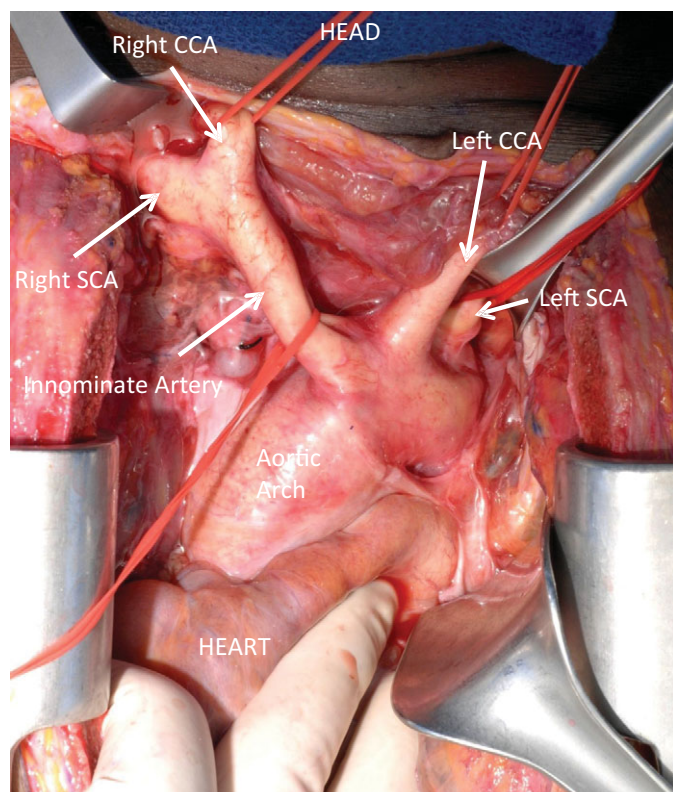


Figure 16.14 Exposure of the innominate artery and the proximal right CCA and right SCA. CCA, common carotid artery; SCA, subclavian artery.

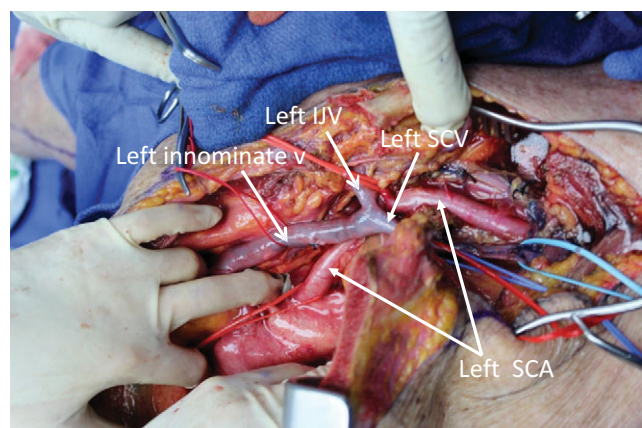


Figure 16.15 (a, b) Satisfactory exposure of the left subclavian artery may require a combination of a median sternotomy with a left clavicular incision (inset). Note the junction of the left internal jugular and left subclavian vein to form the left innominate vein. IJV, internal jugular vein; SCV, subclavian vein.

- Mobilization and isolation of the left subclavian artery may require a combination of a median sternotomy with a left clavicular incision.
- Identify and protect the left vagus nerve as it descends into the mediastinum between the left carotid and the left subclavian arteries, over the aortic arch.

Exposure of the Descending Thoracic Aorta

- Optimal exposure is achieved through a generous left posterolateral incision through the fourth intercostal space.
- During dissection and isolation of the aorta, the esophagus should be identified and protected. It lies on the right side

of the aorta, but as it enters the diaphragm, it courses in front of the aorta.

- The left vagus nerve courses over the aortic arch, between the subclavian and left common carotid arteries. In proximal dissections, it should be isolated and protected.

Management of Mediastinal Venous Injuries

- Ligation of the innominate vein is usually well tolerated. Transient arm edema is the most common complication. Repair of the vein should be considered only if it can be done with lateral venorrhaphy and without narrowing. For an acute injury, especially in the hemodynamically compromised patient, complex reconstruction with synthetic grafts should not be performed.
- Ligation of the SVC is not compatible with life because of the development of massive brain edema. Repair or reconstruction should always be attempted.
- Intraoperative air embolism is a common and potentially lethal complication because of the negative venous pressures in the severely hypovolemic patient. Early occlusion of the venous tear by compression or application of a vascular clamp helps to prevent this complication.

Management of Mediastinal Arterial Injuries

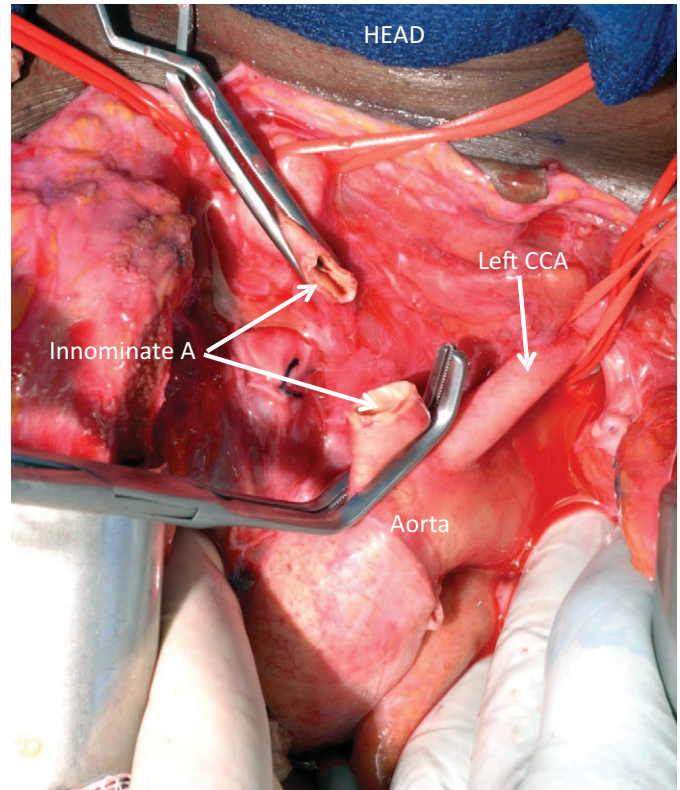
Many patients with injuries to the major mediastinal arteries arrive in extremis. However, ligation of these vessels is not advisable because it may not be compatible with life and is also associated with a high incidence of limb loss. Simple suture-repair is the preferred choice whenever possible, which is often the case with stab wounds. For more complex injuries with tissue loss, usually due to gunshot wounds or blunt trauma, a more complex reconstruction with prosthetic conduit may be required. Damage control procedures using a temporary intra-vascular shunt is ideal for all injuries involving the branches of the aortic arch. However, for injuries involving the aorta, shunting is not technically possible. In these cases, temporary bleeding control and cardiopulmonary bypass may be the only option.

Innominate Artery and Proximal Right Carotid Artery

- Identify the origins of the right subclavian and right common carotid arteries and isolate with vessel loops and vascular clamps for control. Extension of the sternotomy into a right sternocleidomastoid incision is often necessary, in order to achieve good exposure of the right carotid artery.
- Identify and protect the right vagus nerve, as it crosses over the subclavian artery.
- In selected patients with small partial tears in the vessel, primary repair is often possible. Use a 4-0 polypropylene suture for a lateral arteriorrhaphy.
- In most cases with gunshot wounds or blunt injury to the innominate artery, repair using the bypass exclusion technique is required.

- Gently palpate the aortic arch to determine suitability for clamping. A side biting clamp is applied just proximal to the innominate take-off. Resect the injured artery and examine the intima in the proximal end. If the intimal disruption extends into the aortic arch, this area is not suitable for proximal graft placement.

(a)



(b)

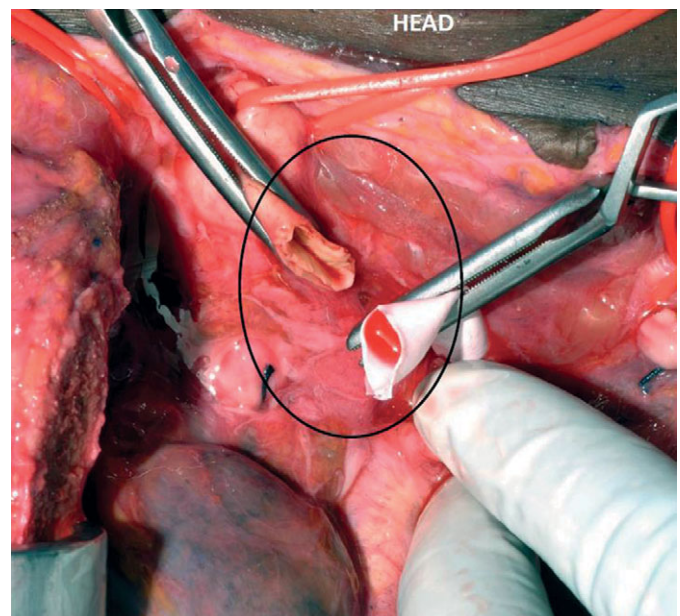


Figure 16.16 Repair of complex injury of the innominate artery with a synthetic graft. A vascular clamp is applied on the proximal innominate artery at its junction with the aortic arch (a). An interposition size 8 synthetic graft is placed (b). CCA, common carotid artery.

- If unable to use the proximal end of the innominate artery, place the clamp on the proximal intrapericardial ascending aorta using a side-biting C clamp. Make an aortotomy with an 11-blade.
- Select an 8–10 mm low-porosity knitted polyester graft and bevel it appropriately to avoid an acute right angle at its origin. This graft is then placed from the ascending aorta to the distal innominate artery immediately proximal to the bifurcation of the subclavian and right carotid arteries. The anastomosis should be performed using a running 4-0 polypropylene suture.
- Restore flow first to the subclavian artery, then to the carotid artery.
- Once the bypass is complete, oversew the proximal innominate artery stump with a 4-0 polypropylene suture.

Proximal Left Carotid Artery

- Proximal exposure is excellent through a median sternotomy. However, a standard left sternocleidomastoid incision may be necessary for adequate distal control.
- Damage control with a temporary arterial shunt is a good option for patients in extremis. This approach may not be technically feasible for very proximal injuries.
- Primary repair is possible for most stab wounds.
- Reconstruction with saphenous vein or synthetic graft is required in most cases after gunshot wounds or blunt trauma. In any complex reconstruction, temporary shunting should be utilized to reduce the risk of ischemic stroke.

Proximal Subclavian Artery

- Exposure and repair of the proximal right and left subclavian arteries requires combined sternotomy and clavicular incisions.
- Damage control with a temporary arterial shunt is a good option in patients in extremis. This approach may not be technically feasible for very proximal injuries.
- Ligation of the subclavian artery should not be considered as an acceptable method of damage control because of the high incidence of limb ischemia and compartment syndrome.
- Primary repair is possible for most stab wounds. However, reconstruction with a size 6–8 mm PTFE graft is required in most gunshot wounds or blunt injuries (see Chapter 9).

Descending Thoracic Aorta

- Exposure of the descendant thoracic aorta is through an extended left posterolateral thoracotomy.

- Placement of a double-lumen tube and deflation of the left lung upon entering the chest cavity improves the exposure of the thoracic aorta.
- The lung is retracted and the posterior mediastinal structures come into view.
- The first step is to obtain proximal control. This is facilitated by first palpating and isolating the left subclavian artery and tracing it back to the aortic arch. Identify and protect the left vagus nerve during the dissection.
- Once the proximal aorta is identified, place a finger carefully between the left carotid and left subclavian artery, around the aorta to create a proximal clamping site. Place umbilical tape around aorta to facilitate clamp placement.
- Once the proximal dissection is complete, obtain distal control. Locate the aorta distal to the hematoma or the bleeding site and incise the pleura over it. Encircle the aorta with finger dissection, followed by an umbilical tape. To avoid avulsion of intercostal vessels, dissection of the aorta should be limited to the area of circumferential control.
- When everything is ready to complete the repair, apply the vascular clamps. Start with the proximal aortic clamp, followed by the distal aortic clamp, then secure the left subclavian artery with a vascular clamp or Rummel tourniquet.

(a)

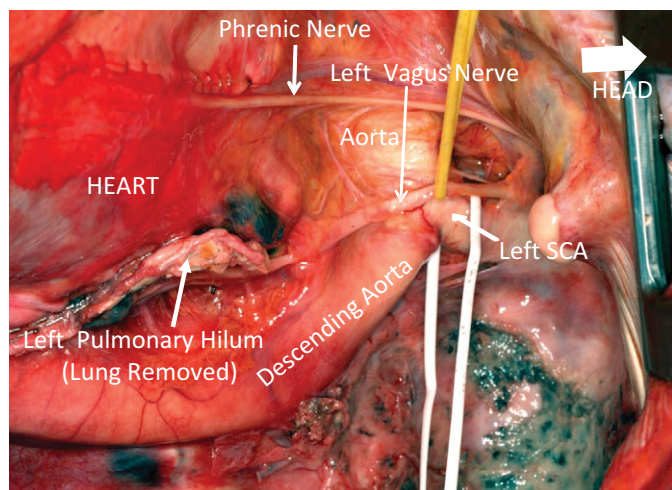
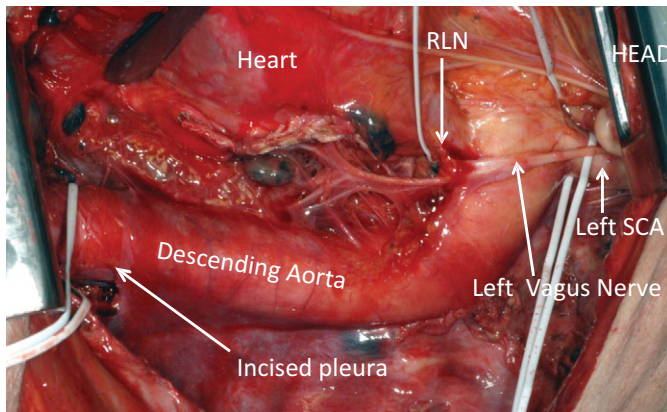


Figure 16.17 (a) Proximal dissection and identification of the origin of the left subclavian artery, which is encircled with a vessel loop (white loop). Note the vagus nerve crossing over the aortic arch (yellow loop). **(b)** The pleura over the distal thoracic aorta is dissected and the aorta is encircled. Note the vagus nerve crossing over the aortic arch, giving the left RLN. **(c)** Proximal and distal control with vascular clamps on the aorta and a Rummel tourniquet on the subclavian artery. RLN, recurrent laryngeal nerve; SCA, subclavian artery.

(b)



(c)

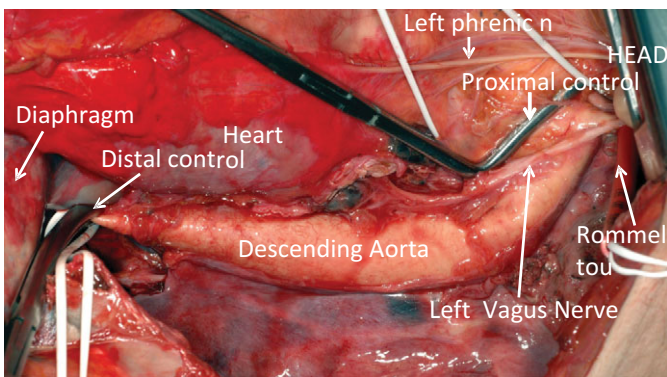


Figure 16.17 (cont.)

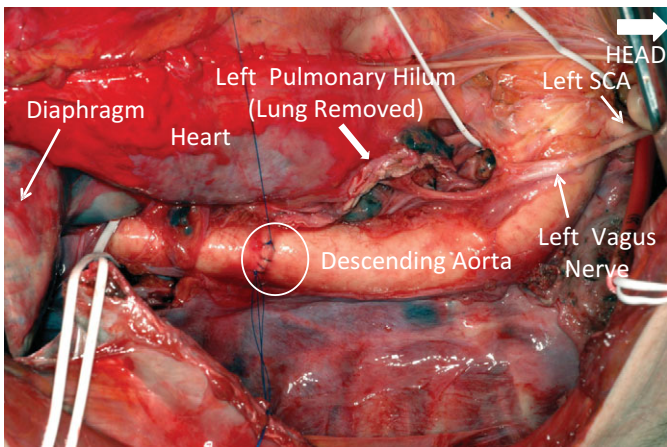


Figure 16.18 Repair of a simple laceration of the descending aorta with a transverse continuous suture (circle), after proximal and distal vascular control. SCA, subclavian artery.

- After the proximal and distal dissections are complete, the area of the aortic injury is dissected and the extent of the damage assessed. Small penetrating injuries may be primarily repaired (4-0 or 5-0 polypropylene sutures).

- Complex injuries or injuries with extensive intimal involvement will require an interposition graft. Identify the ends of the aorta and excise to healthy tissue. Look for bleeding from the intercostals; if identified, oversew with 4-0 polypropylene sutures.
- Sew the proximal graft in first using a double-armed 4-0 polypropylene running suture without pledgets. Once the proximal anastomosis is completed, stretch and cut the graft to an appropriate length and perform the distal anastomosis. Just prior to completion of the distal anastomosis, release the distal clamp to check hemostasis and to de-air the aorta. Complete the distal anastomosis and remove the proximal clamp.

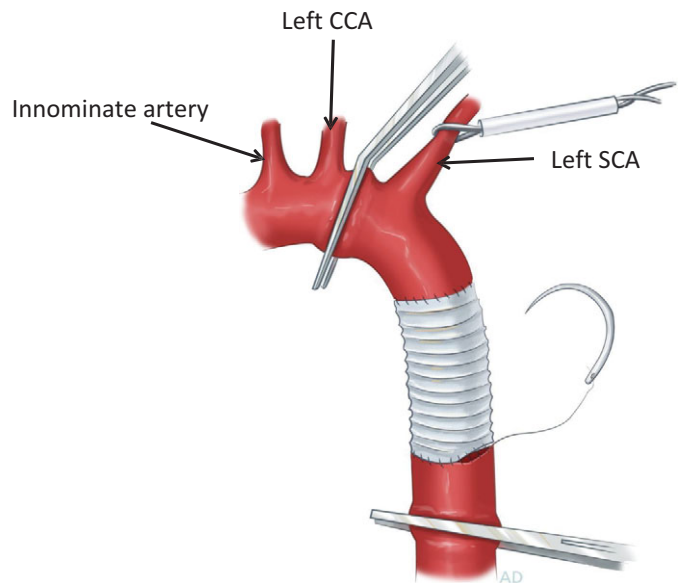


Figure 16.19 Repair of the descending aorta with an interposition graft, after proximal and distal control. CCA, common carotid artery; SCA, subclavian artery.

- Once hemostasis is achieved, cover the graft by closing the mediastinal pleura with absorbable sutures. This excludes the graft from the lung.
- Place chest tubes and close the thoracotomy incision.

Technical Pitfalls

- The most serious and common error is performing the operation without excellent knowledge of the local anatomy.
- Using a double-lumen tube is not mandatory, but will facilitate exposure and repair of the aortic injury.
- Perform the posterolateral thoracotomy through the fourth intercostal space. Choosing the wrong space makes exposure difficult. If exposure using the fourth intercostal space is still inadequate, excise a rib above or below the initial incision.

- After a clamshell incision, both internal mammary arteries are transected. Identify and ligate all four arterial ends.
- There is a significant risk of air embolism in venous injuries. In a hypovolemic patient, it may take only a few seconds. Control the venous injury by compression or clamping as soon as possible.
- The left innominate vein lies under the thymic remnant and surrounding fat. There is a risk of accidental injury to the vein during the exploration of the upper mediastinum.
- There is a risk of iatrogenic injury to the left vagus nerve as it crosses over the aortic arch and between the left carotid and left subclavian arteries during dissection for proximal aortic control.
- During innominate artery reconstruction, restoring blood flow to the carotid artery prior to the subclavian artery could potentially send debris or air to the brain rather than the arm.
- Attempting to obtain proximal aortic control distal to the subclavian artery may make repair difficult, as this leaves a very short proximal aorta on which to sew the graft. Obtaining control distal to the left carotid artery, but proximal to the left subclavian artery provides extra room for repair.
- Be careful while dissecting the distal aorta away from the vertebral column. Stay between the intercostal vessels and minimize superior and inferior dissection to prevent bleeding and avulsion of the intercostal vessels.
- When dissecting out the distal aorta, be sure to palpate and protect the esophagus to prevent injury, and avoid including the esophagus in the distal aortic clamp.

Lungs

Demetrios Demetriades and Jennifer A. Smith

Surgical Anatomy

- The trachea divides into the right and left main bronchi at the level of the sternal angle (T4 level). The right bronchus is wider, shorter, and more vertical compared to the left. The right bronchus divides into three lobar bronchi, supplying the right upper, middle, and lower lung lobes respectively. The left bronchus divides into two lobar bronchi, supplying the left upper and lower lobes.
- The lung has a unique dual blood supply. The pulmonary artery trunk originates from the right ventricle and gives the right and left pulmonary arteries. The right pulmonary artery passes posterior to the aorta and superior vena cava. The left pulmonary artery courses anterior to the left mainstem bronchus. The pulmonary arteries supply deoxygenated blood from the systemic circulation directly to alveoli where gas exchange occurs. These vessels are large in diameter, but supply blood in a low pressure system.

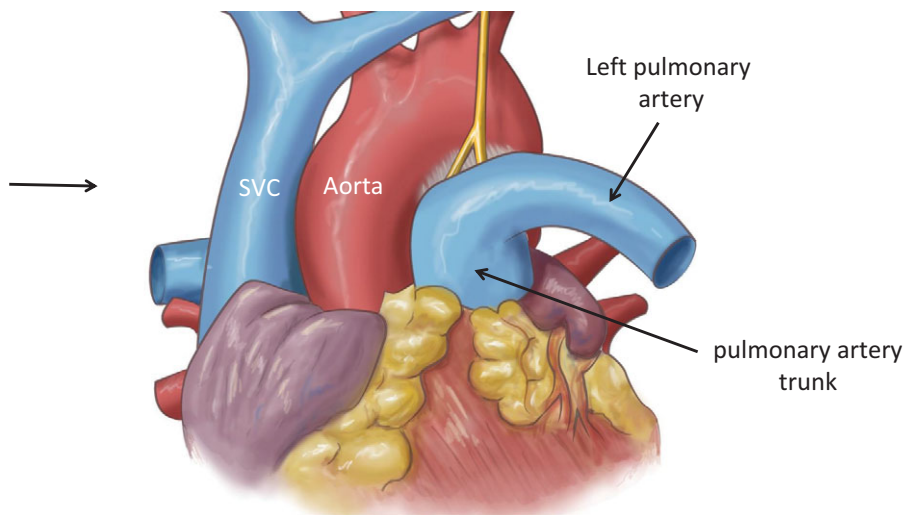
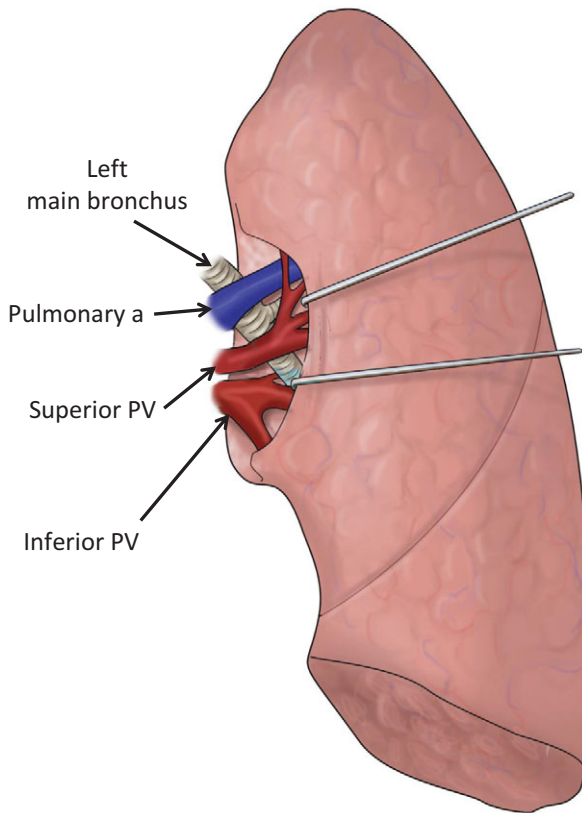


Figure 17.1 The pulmonary artery trunk originates from the right ventricle and gives the right and left pulmonary arteries. The right pulmonary artery passes posterior to the aorta and superior vena cava. SVC, Superior Vena Cava.

- The bronchial arteries arise directly from the thoracic aorta. These vessels are smaller in diameter, and supply the trachea, bronchial tree, and visceral pleura.
- The venous drainage of the lungs occurs from the pulmonary veins. They originate at the level of the alveoli.

There are two pulmonary veins on the right and two on the left. These four veins join at or near their junction with the left atrium usually within the pericardium. These veins carry oxygenated blood back to the heart for distribution to the systemic circulation.

(a)



(b)

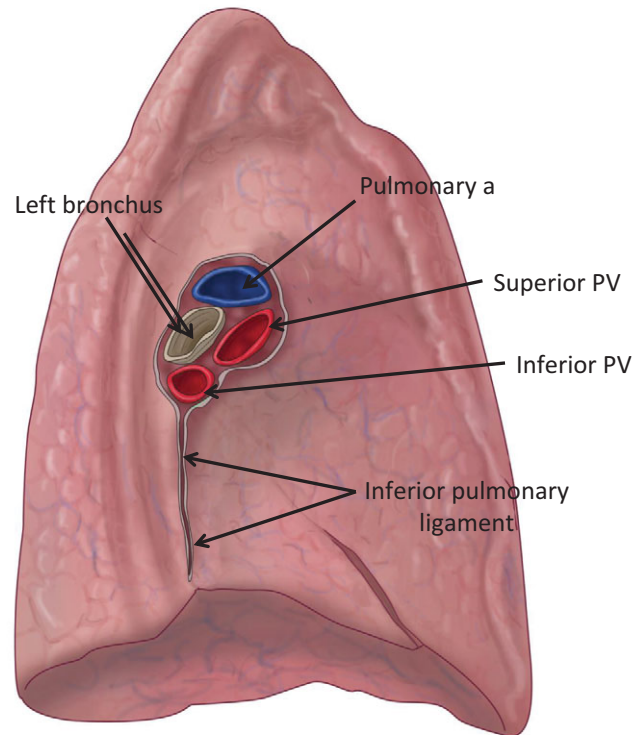


Figure 17.2 (a, b) Anatomy of the left hilum. The pulmonary artery is the superior-most structure within the pulmonary hilum. Note the close relationship between the inferior pulmonary vein and inferior pulmonary ligament. Caution should be taken to avoid injury to the vein during division of the ligament. **(c, d)** Anatomy of the left hilum. The pulmonary artery is the superior-most structure within the pulmonary hilum. Note the close relationship between the inferior pulmonary vein and inferior pulmonary ligament. Caution should be taken to avoid injury to the vein during division of the ligament. PV, pulmonary vein.

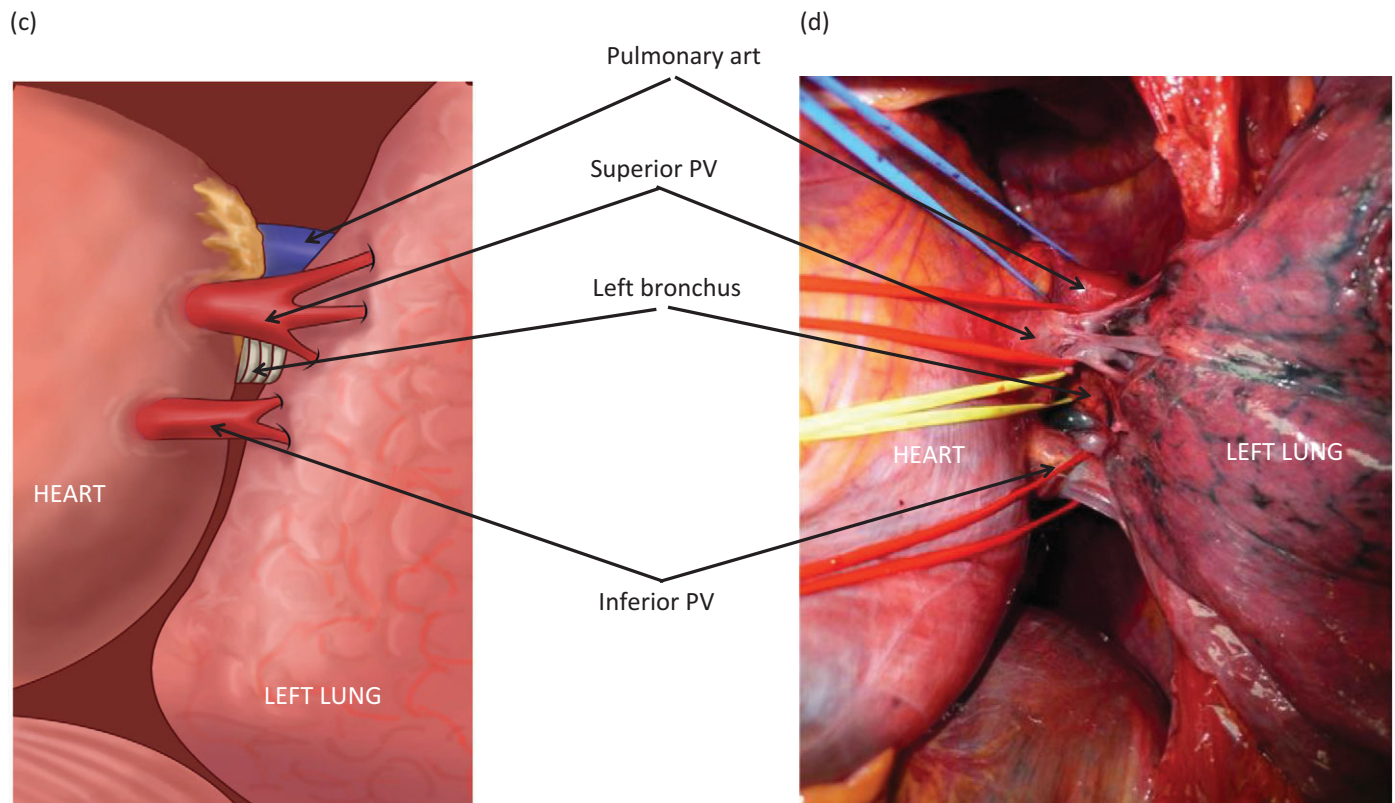


Figure 17.2 (cont.)

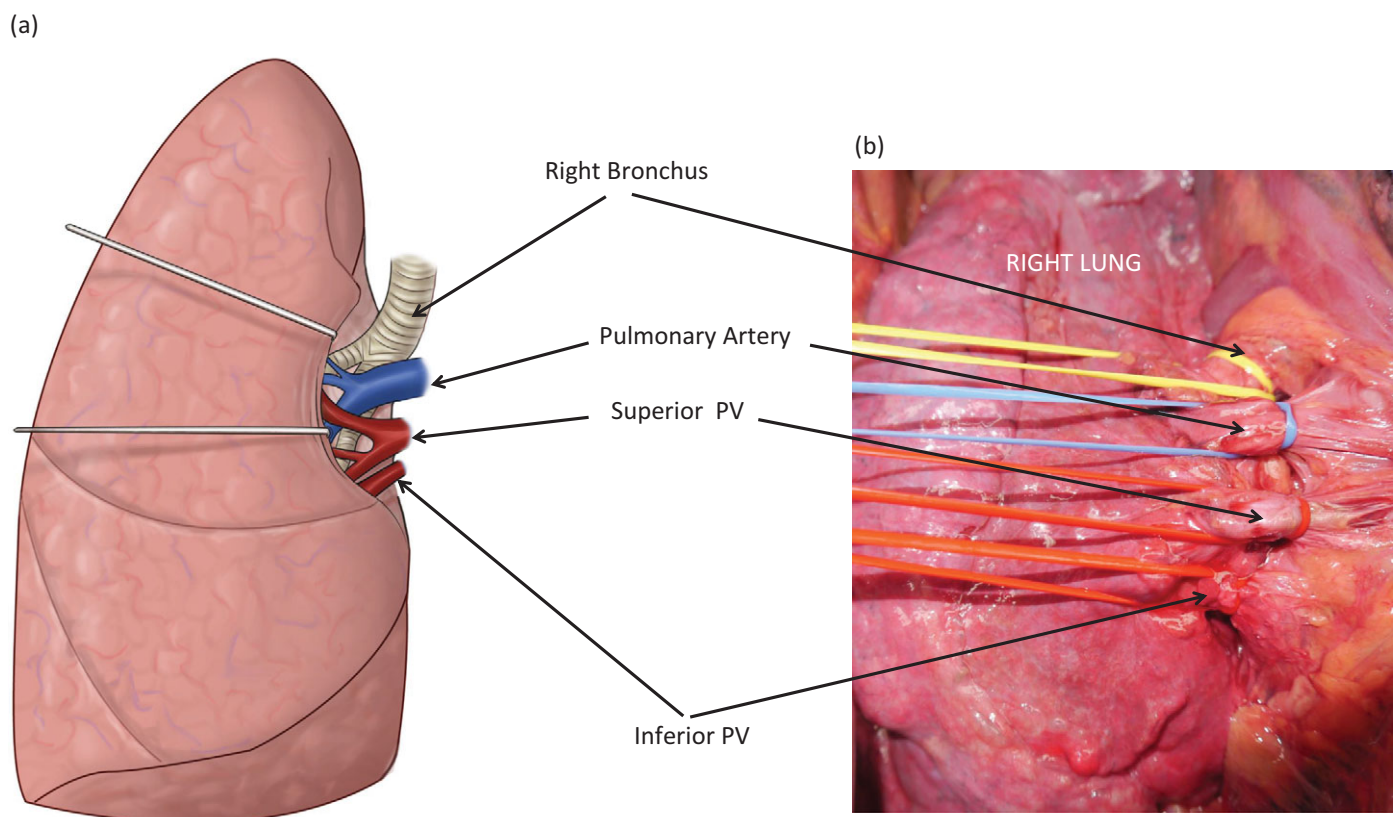


Figure 17.3 (a, b) Anatomy of the right hilum. There are two structures located anteriorly; the pulmonary artery superiorly, and the superior pulmonary vein inferiorly. The posterior-most structure is the right mainstem bronchus. The inferior-most structure is the inferior pulmonary vein.

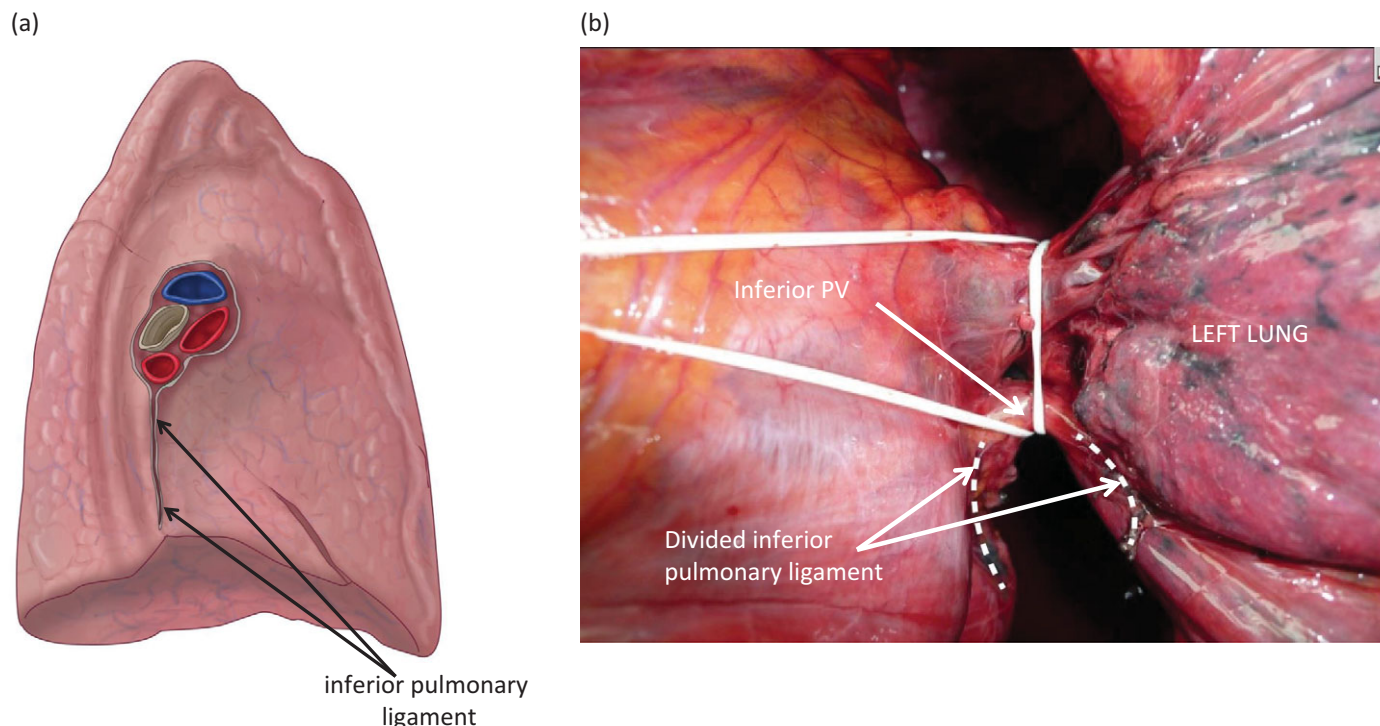


Figure 17.4 (a, b) Left hilar structures and inferior pulmonary ligament. Note the close relationship between the inferior pulmonary vein and inferior pulmonary ligament. Caution should be taken to avoid injury to the vein during division of the ligament.

- The lung is covered superiorly, anteriorly, and posteriorly by pleura. At its inferior border the investing layers come into contact forming the inferior pulmonary ligament that connects the lower lobe of the lung, from the inferior pulmonary vein to the mediastinum and the medial part of the diaphragm. It serves to retain the lower lung lobe in position.

General Principles

- Lungs have high blood flow, but are part of a low-pressure system. In addition, the lung tissue is rich in tissue thromboplastin. This combination results in spontaneous hemostasis from the lung parenchyma in the majority of cases. Hilar or central lung injuries are the most common cause of massive lung hemorrhage, requiring operative management.
- About 80% to 85% of penetrating and more than 90% of blunt trauma to the lungs can safely be managed with thoracostomy tube drainage and supportive measures alone.
- Lung-sparing nonanatomical lung resections are preferable to more extensive anatomical resections.

- Pneumonectomy after trauma is associated with very high mortality.

Special Surgical Instruments

The surgeon should have readily available a standard vascular tray, Finochietto retractor, Duval clamps, Allison lung retractor, and a sternal saw or Lebsche knife.

Anesthesia Considerations

- If the hemodynamic condition of the patient allows, insert a double-lumen tube.
- Maintain low tidal volumes to reduce the risk of air embolism.

Positioning

The patient is placed supine on the operating room table with both arms abducted to 90°. Skin preparation should include the neck, anterior, and bilateral lateral chest walls and the abdomen down to the groins.

Incisions

Median Sternotomy

It is the incision of choice in penetrating injuries to the anterior chest, with suspected cardiac or anterior mediastinal vascular injuries. It provides good exposure of the heart, the anterior mediastinal vessels, both of the lungs, the middle and distal trachea, and left mainstem bronchus. It is quick to perform, relatively bloodless, and causes less postoperative pain and fewer respiratory complications than a thoracotomy. However, it does not allow for good exposure of the posterior mediastinal structures and does not provide adequate access for cross-clamping of the thoracic aorta for resuscitation purposes. The technique is described in [Chapter 14](#), General Principles of Chest Trauma Operations.

Anterolateral Thoracotomy

It is the preferred incision in cases with lung injuries. The technique is described in [Chapter 14](#).

Clamshell Thoracotomy

It is usually performed as an extension of a standard anterolateral thoracotomy to the opposite side, for suspected bilateral lung injuries, superior mediastinal vascular injuries, or cardiac resuscitation and aortic cross-clamping purposes. The technique is described in [Chapter 14](#).

Operative Techniques

- The type of lung operation is determined by the site and severity of lung injury, the shape and direction of a

penetrating lung wound, the hemodynamic condition of the patient, and the experience of the surgeon. The operative techniques may include suturing of the bleeding lung, lung tractotomy, wedge resection, lobectomy, and total pneumonectomy.

- There is a stepwise increase in both mortality and complications with more extensive resections. This is independent of injury severity and the presence of associated injuries. In trauma, nonanatomic lung-sparing resections are preferred over extensive anatomical resections.

Pneumonorrhaphy

- This technique is used to repair small, superficial lung injuries. Following careful individual suture-ligation of any major bleeders and air leaks, the laceration is repaired with figure-of-eight absorbable sutures, on a large tapered needle. Application of tissue glue prior to approximation of the edges of the laceration may improve hemostasis and control minor air leaks.
- In cases with bleeding and air leaks from deep penetrating lung injuries, suturing of the entry and exit wounds should be avoided because of the risk of air embolism, intrapulmonary hematoma, and hemorrhagic flooding of the bronchial tree, including the contralateral lung. These cases should be managed with lung tractotomy or segmental resection.

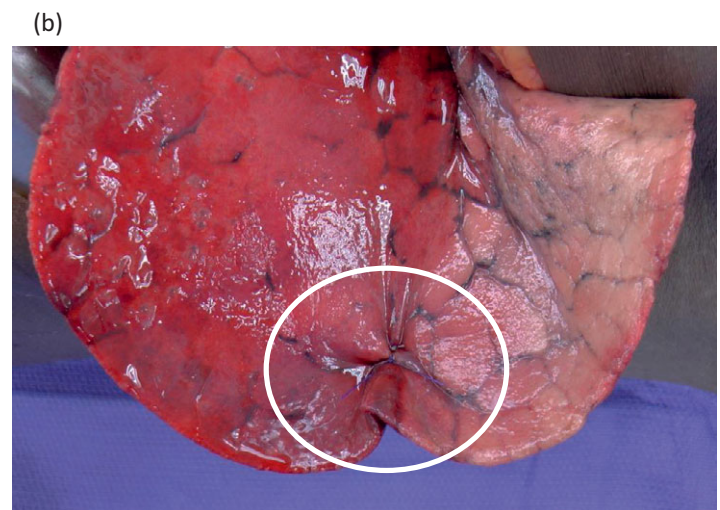
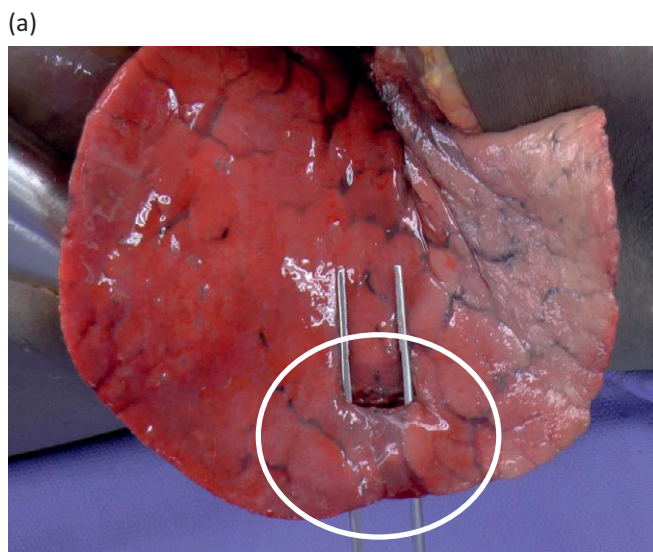


Figure 17.5 (a) Peripheral stab wound to the lung (circle), amenable to primary repair. (b) Pneumonorrhaphy with figure-of-eight sutures.

Lung Tractotomy

- This is the procedure of choice in cases with bleeding and/or major air leaks from deep, penetrating injuries. Tractotomy is not indicated in suspected hilar injuries. These injuries usually require lobectomy or total pneumonectomy.
- The wound tract is opened with a GIA stapler. Any significant bleeders or air leaks are suture-ligated under direct visualization. Application of tissue glue may be helpful in decreasing any diffuse bleeding and minor air leaks. The tract may be closed with figure-of-eight absorbable sutures on a large tapered needle.

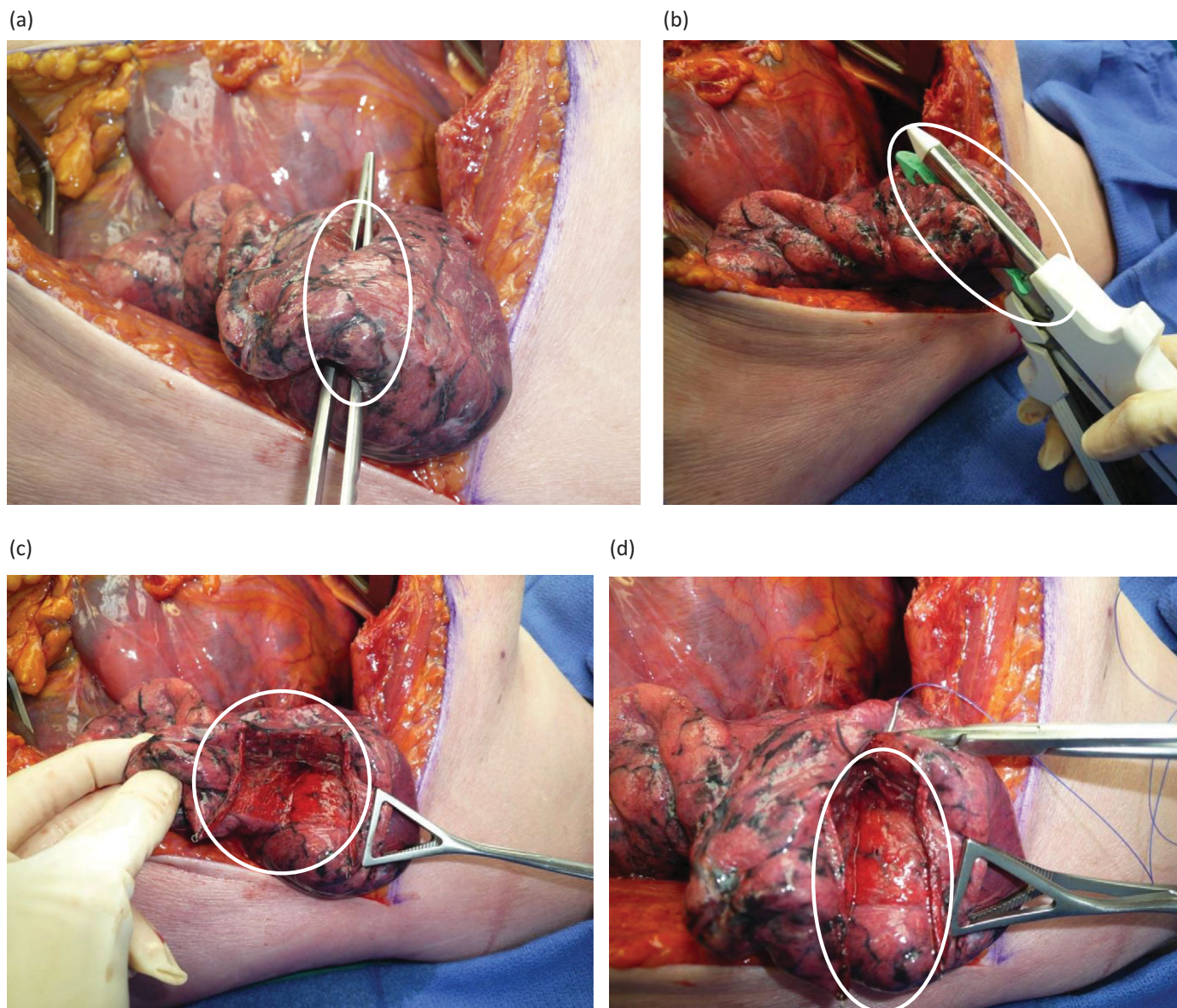


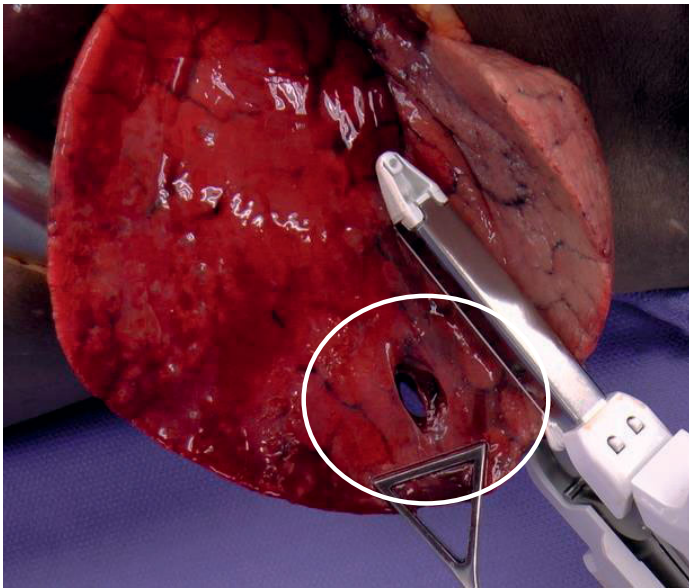
Figure 17.6 (a) Penetrating wound through lung parenchyma. (b) Technique of stapled tractotomy using a GIA stapler. (c) Opened tract after tractotomy. (d) Overseeing small vessels and air leaks in the tract.

- On rare occasions, tractotomy may devascularize segments of the lung, resulting in subsequent ischemic necrosis and lung abscess. The tractotomy should be performed parallel to the vascular supply whenever possible. The lung adjacent to the tractotomy should be always assessed for viability and any questionable tissue should be resected.

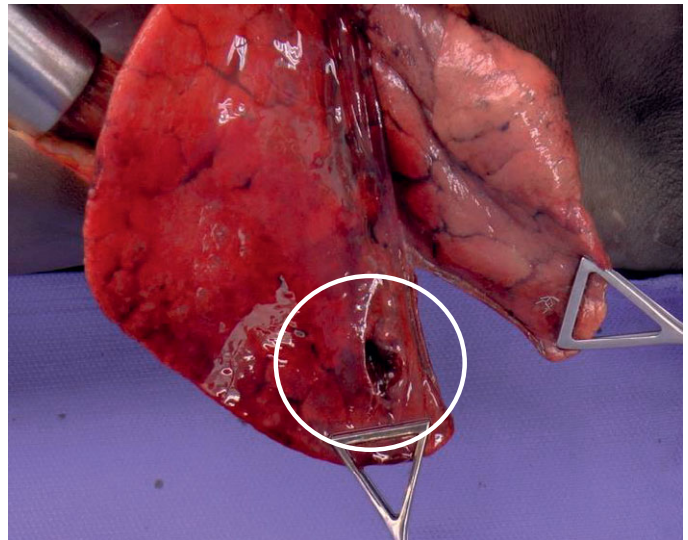
Wedge Resection

For larger peripheral injuries, the injured lung may be resected nonanatomically. Using a GIA stapler, “wedge out” the injured tissue. Any persisting bleeding or air leaks can be managed with additional sutures and/or tissue glue. Alternatively, if a stapling device is not available, the injured tissue may be placed between clamps and the tissue “cut out.” The edges are then oversewn using a running technique.

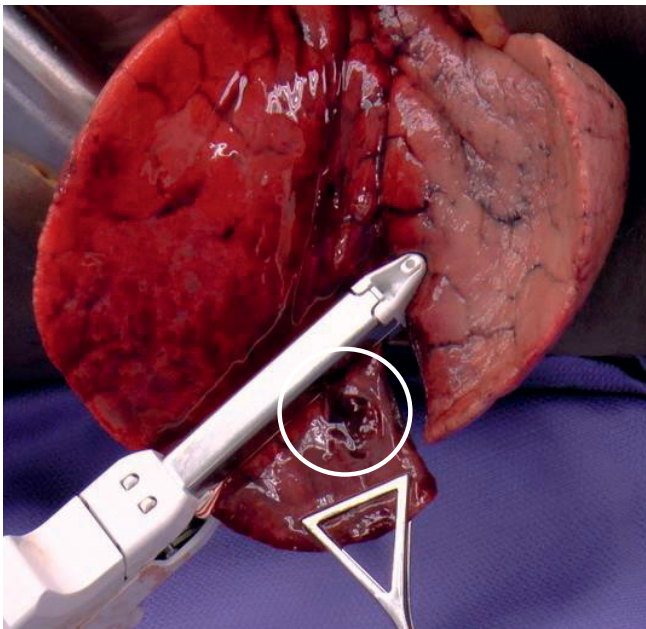
(a)



(b)



(c)



(d)

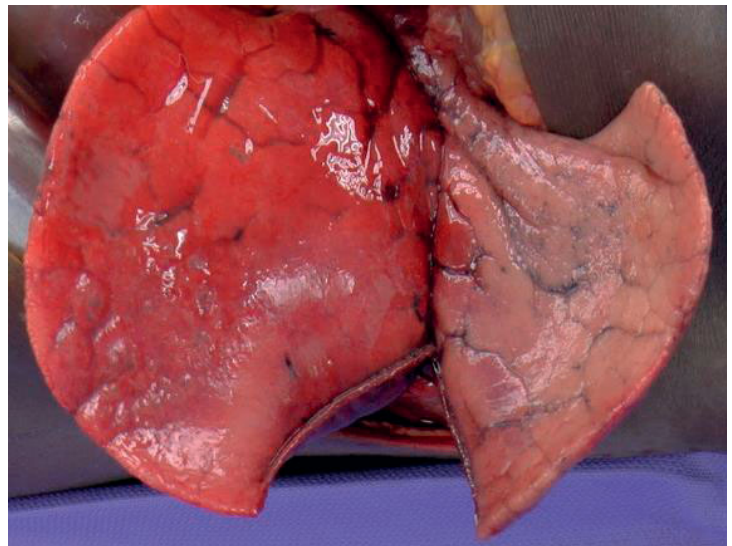
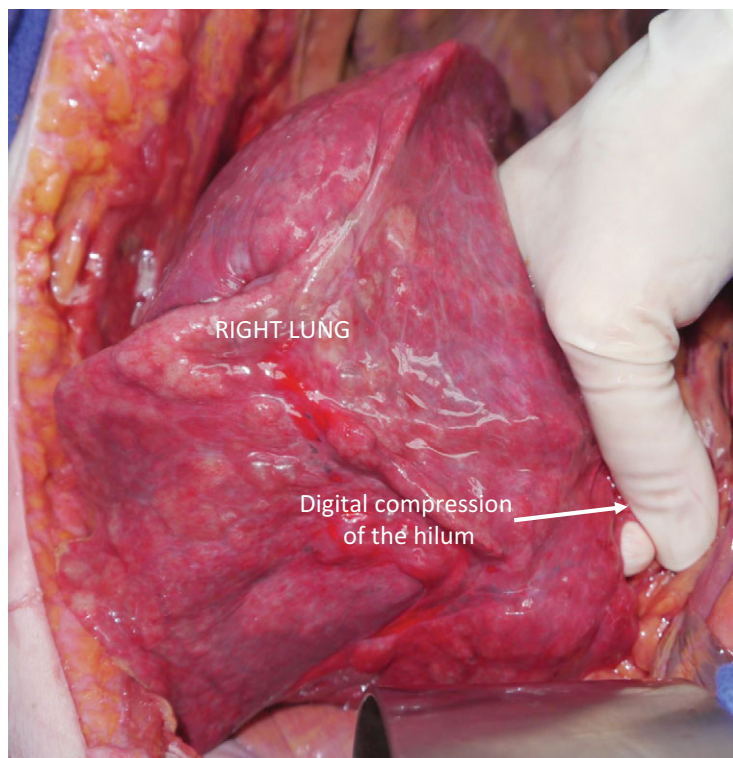


Figure 17.7 (a, b) Wedge resection of lung parenchyma using a GIA stapler to treat a peripheral lung laceration (arrow). (c) Completed wedge resection of the lung.

Nonanatomic Lobe Resection

- After temporary bleeding control with digital compression or application of a vascular clamp around the hilar structures, the hilar vessels are dissected free and the injury is identified. Depending on the anatomical location of the injury, the need for a lobectomy or pneumonectomy is determined.
- Anatomic lobe resection is rarely used in trauma and has been replaced by nonanatomical resection, preserving as much normal lung parenchyma as possible.

(a)



(b)

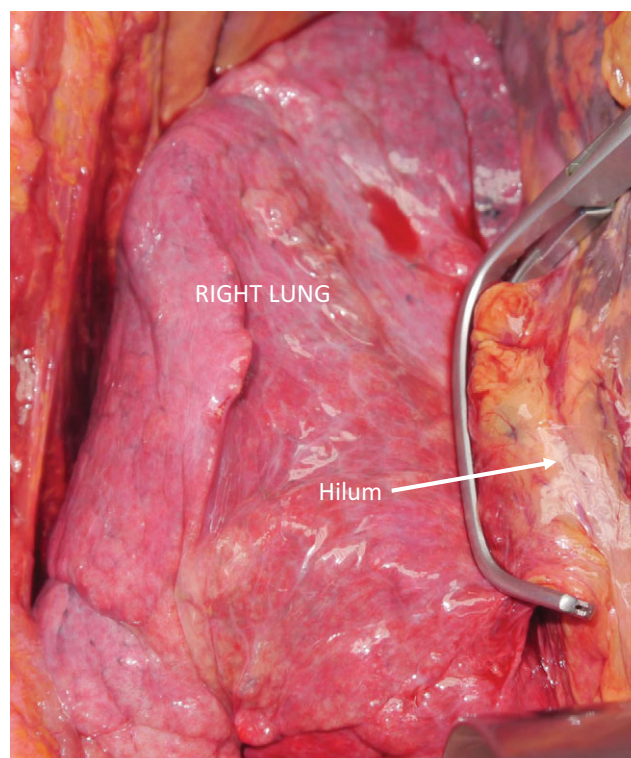
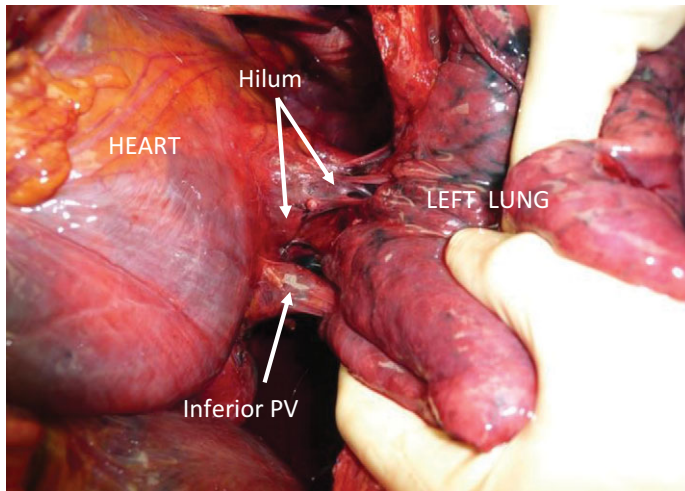


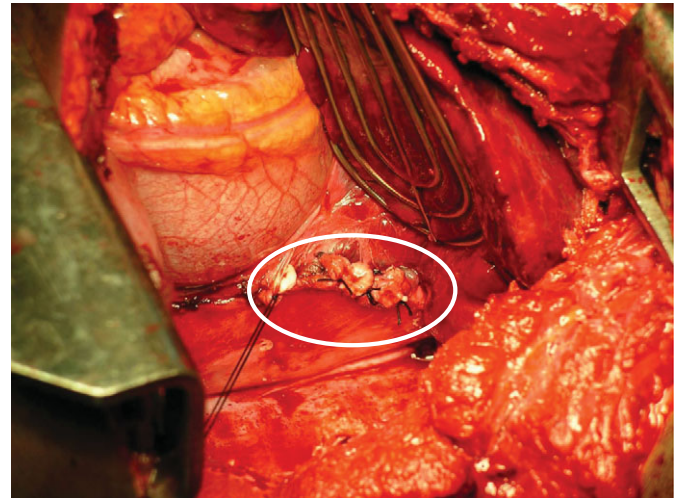
Figure 17.8 Temporary bleeding control of the lung with: (a) Manual compression of the right hilum. (b) Application of a vascular clamp around the right hilum.

- During lower lobe resections, the inferior pulmonary ligament should be divided.
- The resection is best accomplished using a TA stapling device. Before release of the stapler, two stay sutures or Allis forceps are applied to the stump in order to prevent retraction. Once the stapler is released, the suture line can be held using the stay suture to inspect for and control any bleeding or air leaks.
- During the procedure, care should be taken to avoid devascularization of the remaining normal lung parenchyma.
- After resection of the lower lobe, avoid torsion of the remaining upper lobe. Failure to recognize this problem results in ischemic necrosis of the normal lobe. The remaining lung parenchyma can be tacked into place using superficially placed 3-0 sutures on a tapered needle.

(a)



(b)



(c)

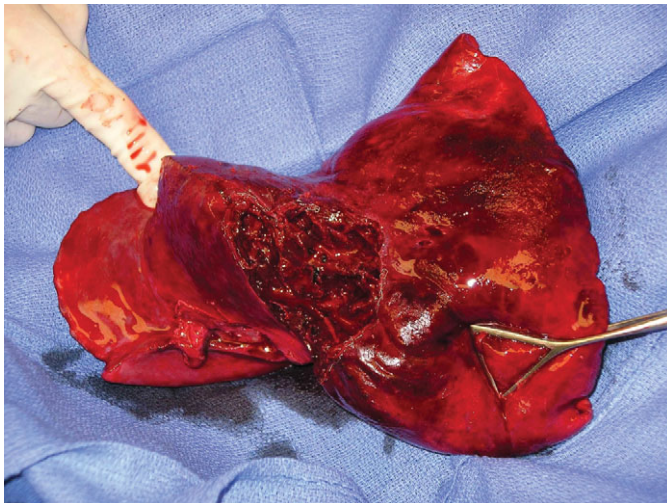


Figure 17.9 (a) Dissection of the hilar vessels to determine the need for lobectomy or total pneumonectomy. (b) En masse stapled left lower lobectomy. If necessary, additional sutures may be placed on staple line for better hemostasis and control of air leaks (circle). (c) Stapled left lower lobectomy specimen.

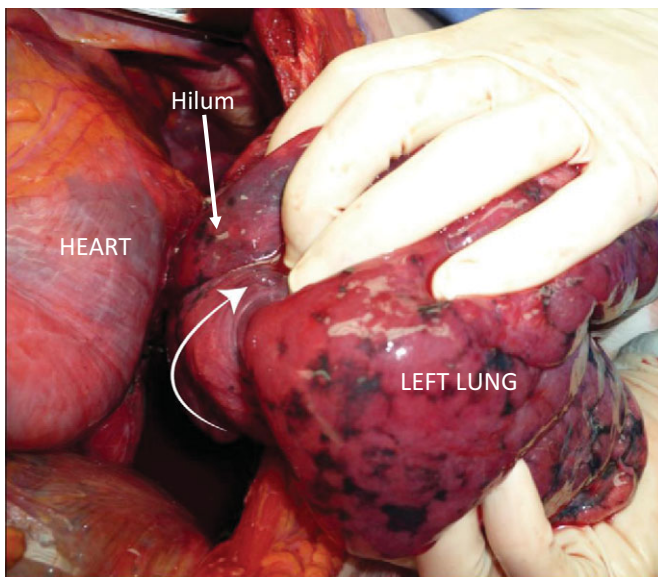


Figure 17.10 Torsion and ischemic necrosis of a normal left upper lung lobe following lower lobe removal.

Pneumonectomy

- A total pneumonectomy may be necessary in severe hilar injuries not amenable to repair or lobectomy.
- In hilar vascular injuries, the patient is usually hemodynamically unstable and there is severe active bleeding. The fastest way to achieve temporary bleeding control is digital compression of the hilum and subsequent application of a vascular clamp, as described above. This maneuver is critical for effective bleeding control, and prevention of air embolism and hemorrhagic flooding of the normal bronchial tree. Acute occlusion may aggravate the hemodynamic condition of the patient because of acute right sided cardiac strain. An alternative to clamping the hilum is to perform a “hilar twist” after release of the inferior pulmonary ligament. The whole lung is twisted 180° around the hilum.

(a)



(b)

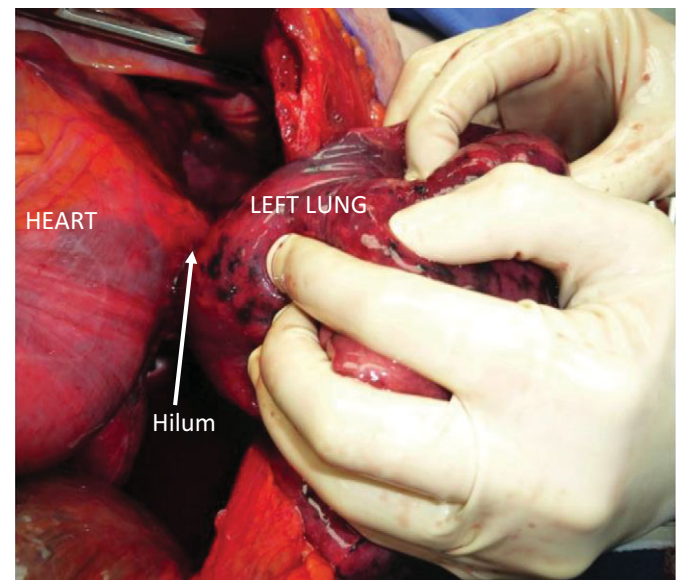


Figure 17.11 (a) Hilar twist for temporary control of hilar bleeding. (b) After division of the inferior pulmonary ligament to mobilize the lung, the lung is grasped in its entirety and rotated 180° in a clockwise direction.

- Pneumonectomy normally involves individual isolation, ligation, and division of the hilar structures. However, this approach is time-consuming and requires significant technical skills and experience. In the unstable trauma patient, an acceptable alternative to the anatomical pneumonectomy is the en masse stapled pneumonectomy.
- The en masse pneumonectomy can be rapidly performed using a TA stapler.
 - The main bronchus should be divided as close to the carina as possible to avoid pooling of secretions and reduce the risk of breakdown of the stump.
 - Following division of the inferior pulmonary ligament, the hilum is isolated and the index finger is placed around it.
- After application and firing of the TA stapler around all hilar structures, the vessels and bronchus are divided approximately 0.5 cm above the instrument.
- Two figure-of-eight stay sutures or two Allis forceps are placed at the two corners of the stump, before the stapler is released. This prevents retraction of the stump after the removal of the stapler and facilitates identification and control of any bleeding or air leaks.
- Buttressing of the stump with adjacent tissues, such as the pericardial fat pad, parietal pleura, or intercostal muscle flap may be used.
- Total pneumonectomy is associated with a very high mortality, usually due to hemorrhage or acute right cardiac failure.

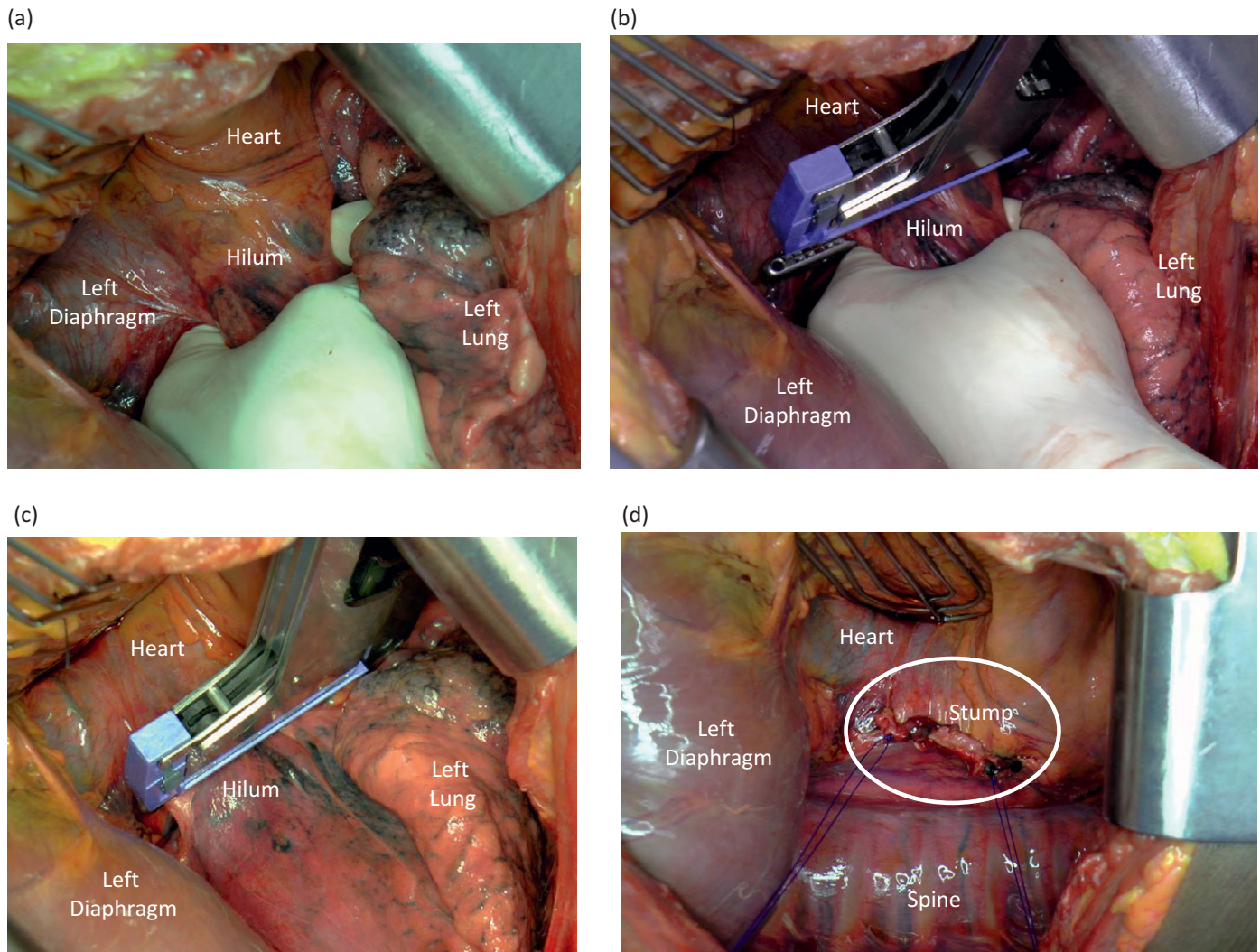


Figure 17.12 Technique of en masse stapled total pneumonectomy: (a) Manual hilar control after division of the inferior pulmonary ligament. (b) A TA stapler is placed around the structures contained within the pulmonary hilum, and fired. (c) The TA stapler is fired and the vessels and bronchus are divided with a scalpel approximately 0.5 cm above the instrument. (d) Two stay sutures or Allis tissue forceps are placed on the stump prior to removal of the stapling device to prevent retraction of the stump. Any bleeding or air leaks can be controlled with additional figure-of-eight absorbable sutures.

Closure

The techniques of sternotomy or thoracotomy closure are described in [Chapter 14](#).

Complications

Air Embolism

- This is a potentially lethal complication and may occur in deep penetrating or hilar injuries involving both the bronchial tree and the pulmonary veins.
- Suturing of the entry and exit wounds of a deep tract creates the ideal conditions for air embolism and should never be done. The appropriate procedure is a tractotomy or a resection.
- Air embolism should be suspected when the patient develops arrhythmias or cardiac arrest. Sometimes, air bubbles may be seen in the coronary veins.
- In suspected air embolism, the patient is placed in the Trendelenburg position, the apex of the heart is elevated and both ventricles are aspirated.

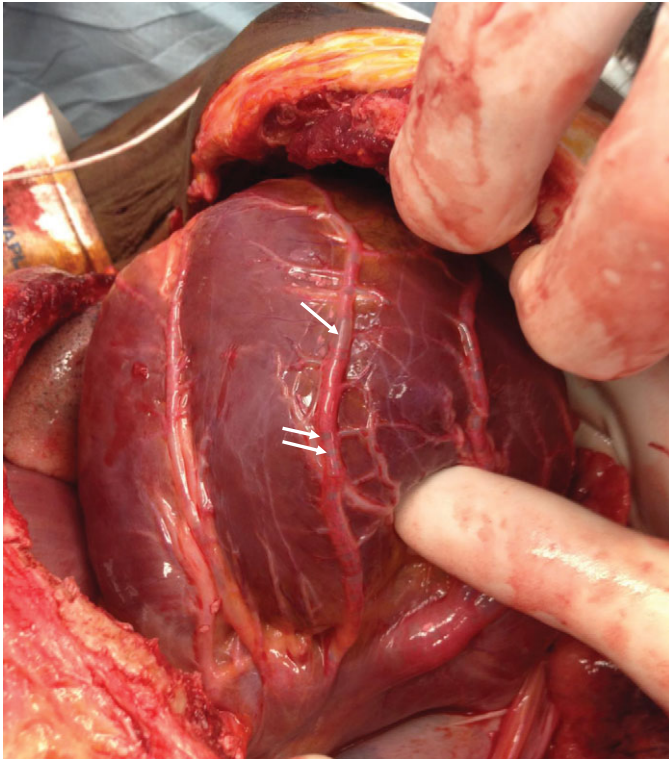


Figure 17.13 Massive air embolism with air bubbles seen in the coronary veins (arrows).

Right Heart Failure

- Occurs when a large volume of lung parenchyma is removed acutely. The volume of blood is now distributed over a smaller volume of parenchyma. This complication requires careful fluid status titration and cardiac output support with the use of inotropes.

Pitfalls

- Suturing of the entry and exit wounds of a deep tract creates the ideal conditions for air embolism and should never be done. The appropriate procedure is a tractotomy or resection.
- During lung tractotomy or nonanatomic resection, portions of the residual lung may become ischemic and necrotic. Orient the tractotomy or resection lines parallel to the vessels and check the residual lung for viability.
- During stapled lobectomy or total pneumonectomy, the hilar stump retracts and can make identification of any persistent bleeding difficult. This may be life threatening if the stapler misfires. Never release the stapling device before placement of two stay sutures or Allis forceps on the stump.
- Anatomic lung resections have limited or no role in trauma. Perform nonanatomic, lung-preserving resections.
- During division of the inferior pulmonary ligament, there is a risk of injury to the inferior pulmonary vein. Proceed cautiously and divide only the semi-transparent part of the ligament.
- After major lung resections, it is essential to reduce the tidal volume accordingly. Also, restrict fluid administration because many patients develop acute right cardiac failure. This is a common cause of postoperative death.
- After major lung operations, perform a bronchoscopy routinely to aspirate any blood from the remaining and contralateral bronchial tree.
- The main bronchus should be divided as close to the carina as possible to avoid pooling of secretions and reduce the risk of breakdown of the stump.

Thoracic Esophagus

Anthony W. Kim and Caroline Park

Surgical Anatomy

- The esophagus is approximately 25 cm in length and begins at the level of the C6 vertebra. The external landmark is the cricoid cartilage. It terminates 2–3 cm below the diaphragmatic hiatus, which corresponds to the T11 vertebra.
- The esophagus is divided into three parts: cervical, thoracic, and intra-abdominal. The cervical esophagus begins approximately 15 cm from the upper incisors and is approximately 6 cm long. The thoracic esophagus begins approximately 23 cm from the incisors and is approximately 15 cm in length. The intra-abdominal esophagus begins approximately 38 cm from the incisors at the diaphragmatic hiatus and extends for 2–3 cm distally before becoming the gastric cardia.
- The thoracic esophagus rests on the thoracic spine and the longus colli muscles. It passes posterior to the trachea, the tracheal bifurcation, the left main stem bronchus, and the left atrium. It descends to the right of the thoracic aorta and moves anterior to the aorta, just above the diaphragm (Figures 18.1a and 18.1b).
- The azygos vein lies in front of the bodies of the lower thoracic vertebrae and to the right of the esophagus. At the level of the bifurcation of the trachea, it arches anteriorly to drain into the superior vena cava, just before it enters the pericardium.
- The hemiazygos vein passes from the left side of the spine to the right, after crossing the spine and travelling behind the aorta, esophagus, and thoracic duct, to drain into the azygos vein.
- The thoracic duct lies between the esophagus, the aorta, and the azygos vein before crossing over, just below the level of the tracheal bifurcation, to the left hemithorax, where it drains into the left subclavian vein.

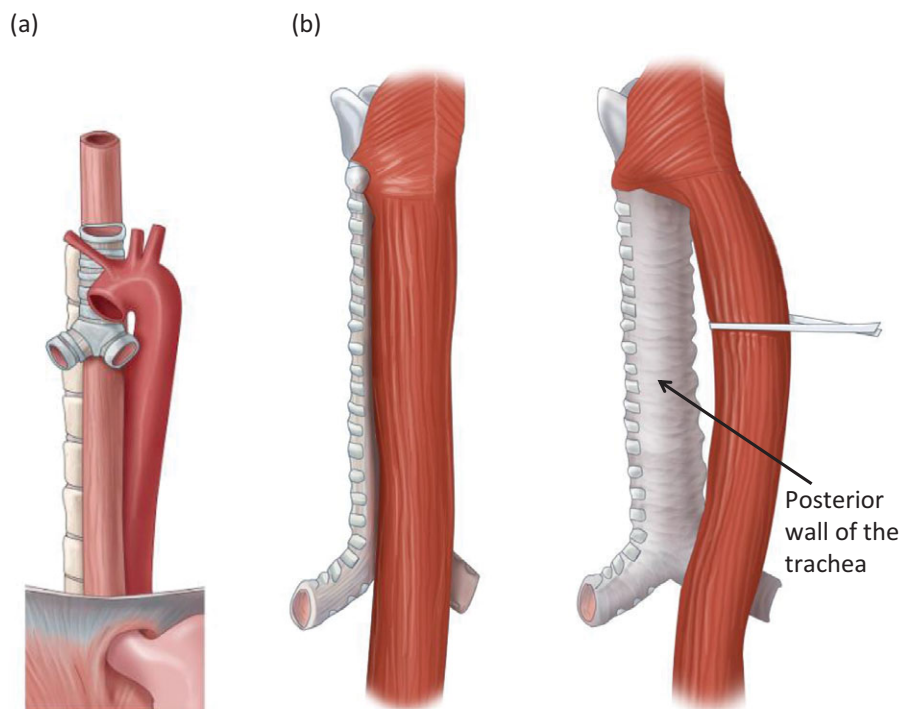


Figure 18.1 (a) Anatomy of the esophagus and its relationship with the spine, trachea, and thoracic aorta. (b) Anatomical relationship between the cervical and upper thoracic esophagus and the larynx and trachea.

- The esophagus does not have a serosal layer. This increases the risk of anastomotic leaks.
- The arterial and venous blood supply and drainage of the esophagus are segmental. The cervical esophagus is supplied by branches of the inferior thyroid artery. The upper thoracic esophagus is supplied by the inferior thyroid artery and an anterior esophagotracheal branch directly from the aorta. The middle and lower esophagus receives its arterial supply directly from the aorta via a bronchoesophageal branch. The lower esophagus and intra-abdominal esophagus portions are supplied by small branches from the left gastric artery and the left inferior phrenic artery.
- The parasympathetic innervation of the esophagus is through the vagal nerves. The right and left recurrent laryngeal nerves ascend in the tracheoesophageal groove, giving off branches to both the trachea and the cervical and upper esophagus. The vagal nerves join with the fibers of the sympathetic chain to form the esophageal plexus. Together with the esophagus, the vagi pass through the diaphragm and continue along the lesser curvature of the stomach.
- The sympathetic innervation comes from the cervical and thoracic sympathetic chains.

General Principles

- Most esophageal injuries can be repaired with suturing or a limited resection and primary anastomosis. In rare cases with extensive soft tissue loss or delayed diagnosis, it may be necessary to perform resection and reconstruction with gastric pull up or colon interposition. These complex procedures will not be discussed in this chapter.
- The primary repair or anastomosis should be tension-free and the edges viable and adequately perfused. Important technical principles for primary repair include:
 - Debridement of all injured, ischemic, and necrotic or infected tissue.

- The muscular layer is incised longitudinally, superiorly and inferiorly to the injury to expose the entire extent of the mucosal injury. Primarily repair the mucosa with absorbable interrupted sutures.
- The muscularis layer can be repaired with interrupted nonabsorbable sutures.
- Avoid narrowing the esophageal lumen.
- Reinforce the primary repair with well-vascularized adjacent tissue flaps.
- Place drains adjacent to the repair.
- Consider placement of a draining gastrostomy tube and a jejunostomy tube for nutritional support.

Special Surgical Instruments

- General thoracic tray (Allison lung retractor, Bethune rib shears, Duval lung forceps, Davidson scapula retractor, Finochietto retractor)
- 1" Penrose drain, thoracostomy tubes
- Headlight

Anesthesia Considerations

- Single lung ventilation is critical for exposure of the thoracic esophagus.
- Bougie or nasogastric tube placement

Patient Positioning

- Upper and middle thoracic esophageal injuries: Left lateral decubitus (right side up)
- Lower thoracic esophageal injuries: Right lateral decubitus (left side up)
- Supine for patients undergoing a laparotomy for intra-abdominal esophageal injuries
- For lateral decubitus positioning, ensure that:
 - An axillary roll is placed in the axilla
 - Male genitalia is not compressed
 - Padding is placed between the knees

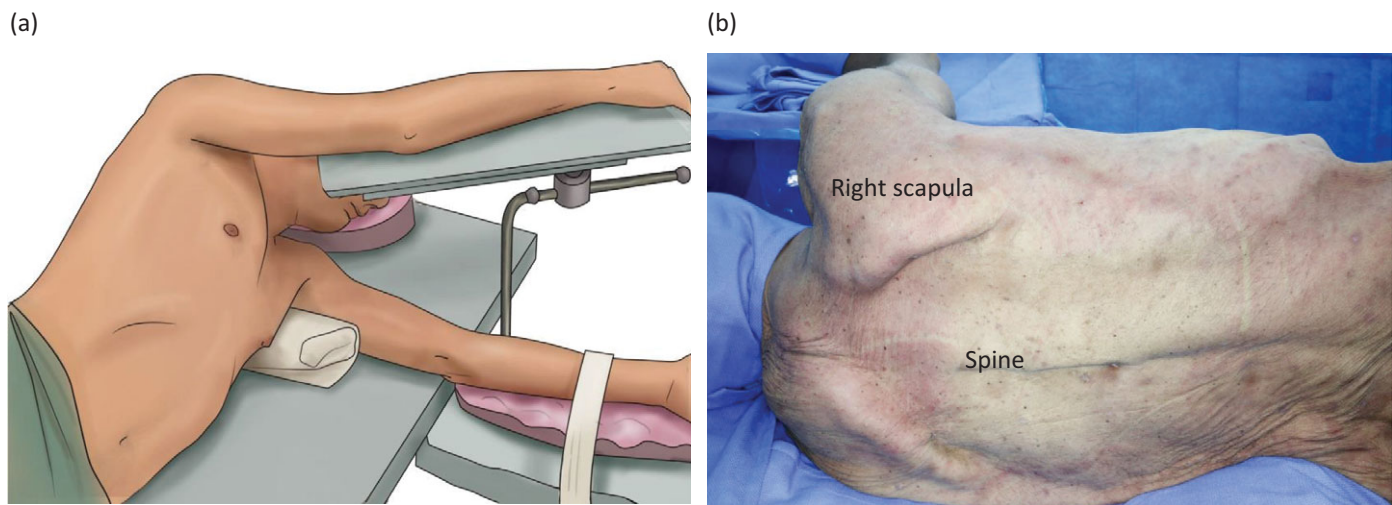
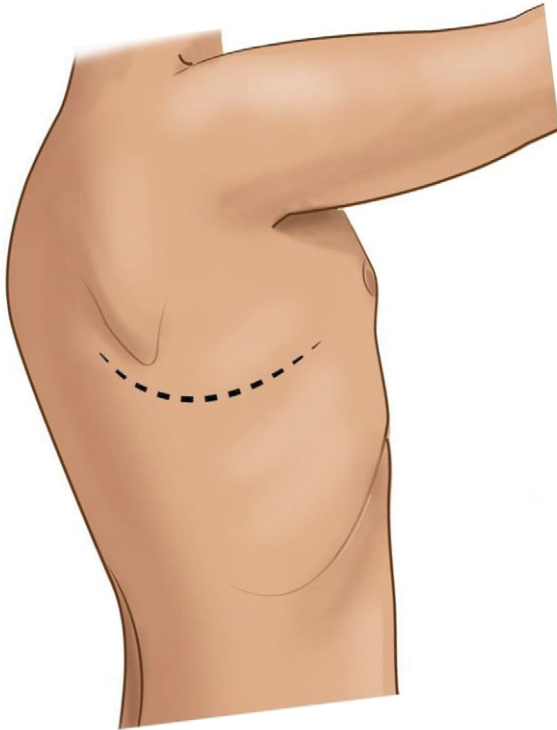


Figure 18.2 (a) Positioning of patient for a right posterolateral thoracotomy. (b) Posterior view of the patient with the hip flexed, the right arm slightly flexed at the elbow. All bony prominences should be sufficiently padded.

Incisions

- Choice of incision depends on the location of the injury.
- Cervical esophagus: Standard left neck incision along the sternocleidomastoid muscle (See [Chapter 7 Neck Operations for Trauma: General Principles](#)).
- Upper and middle thoracic esophagus: right posterolateral thoracotomy in the fifth or sixth intercostal space.
- Lower thoracic esophagus: left posterolateral thoracotomy in the seventh or eighth intercostal space.
- Intra-abdominal esophagus: laparotomy.

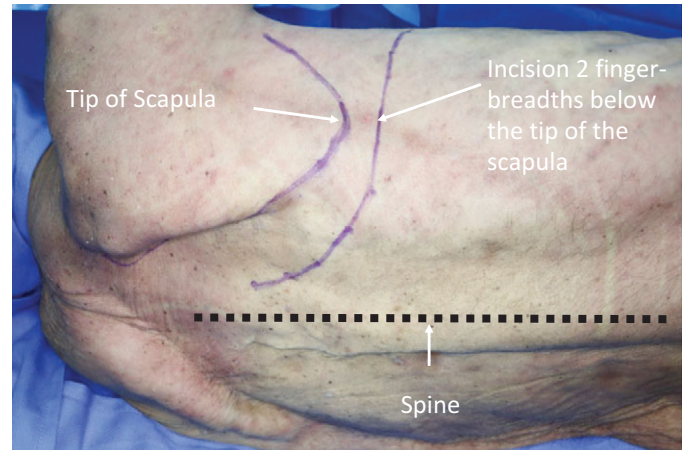
(a)



Standard Posterolateral Thoracotomy

- Identify the scapula border and mark the skin ([Figure 18.3a](#)).
- The skin incision for a posterolateral thoracotomy extends from the anterior axillary line, coursing about 1–2 fingerbreadths below the tip of the scapula, and extends posteriorly and cephalad midway between the spine and the medial border of the scapula ([Figure 18.3a](#) and [18.3c](#)).

(b)



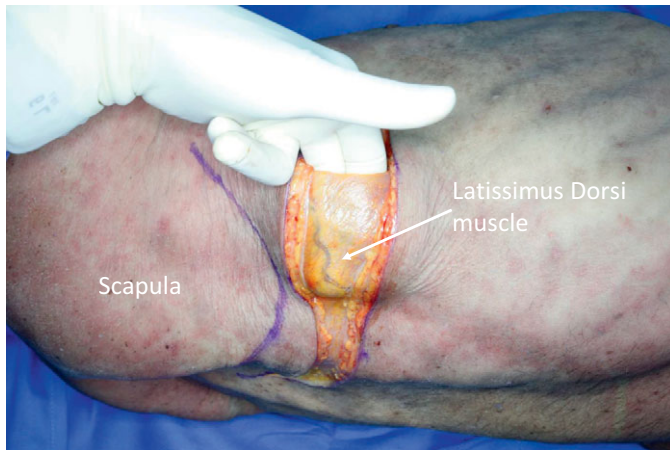
(c)



Figure 18.3 (a–c) The skin incision for a posterolateral thoracotomy extends from the anterior axillary line, coursing about 1–2 fingerbreadths below the tip of the scapula, and extends posteriorly and cephalad midway between the spine and the medial border of the scapula.

- Divide the subcutaneous tissue. Identify and divide the latissimus dorsi muscle, but preserve the rhomboid muscle posteriorly. This muscle can be avoided by locating the “empty triangle” between the two muscle groups.

(a)



(b)

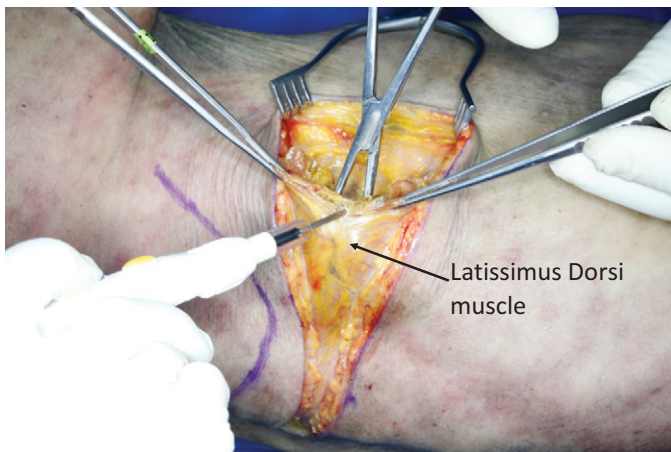


Figure 18.4 (a, b) Exposure and division of the latissimus dorsi muscle.

- Use the scapula retractor and palpate the number of rib spaces ([Figure 18.5](#)).
- Divide the intercostal muscle from its insertion site on the superior border of the sixth rib to avoid the neurovascular bundle coursing along the inferior rib border ([Figure 18.6a](#)).
- To avoid rib fracture during Finochietto retractor placement, one may consider removing a 2 cm segment of rib using the Bethune rib shears. If further exposure is needed a subtotal of rib resection may be done.
- Place the Finochietto retractor, bluntly dissect the intercostal muscle flap off the rib with gentle downward retraction to avoid injury to the neurovascular bundle. Ligate the anterior aspect of the intercostal muscle flap and tag with a nonabsorbable suture for future use as a buttressed repair ([Figure 18.6b](#) and [18.6c](#)).

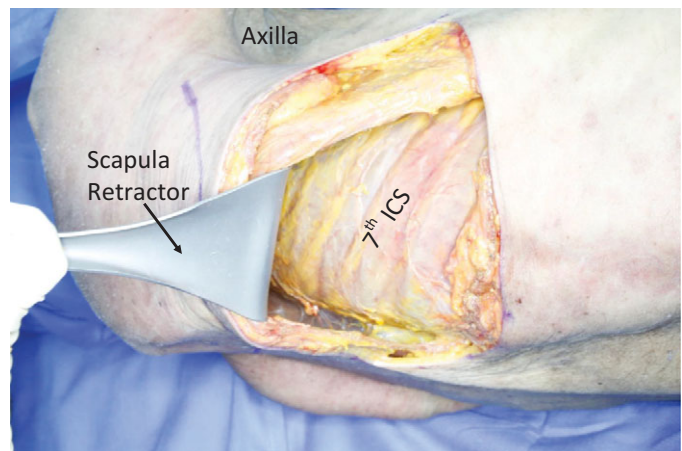
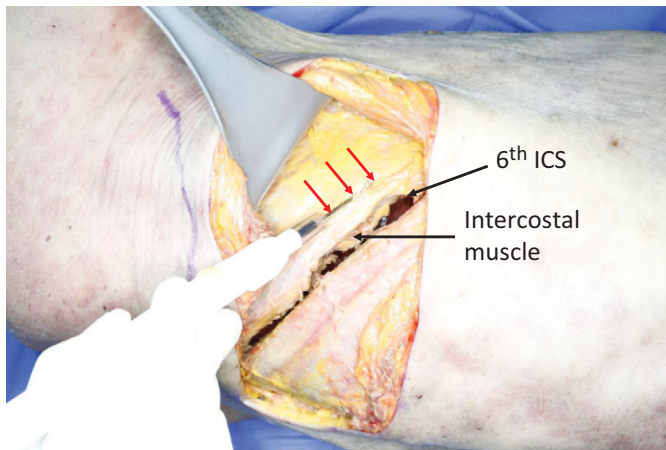
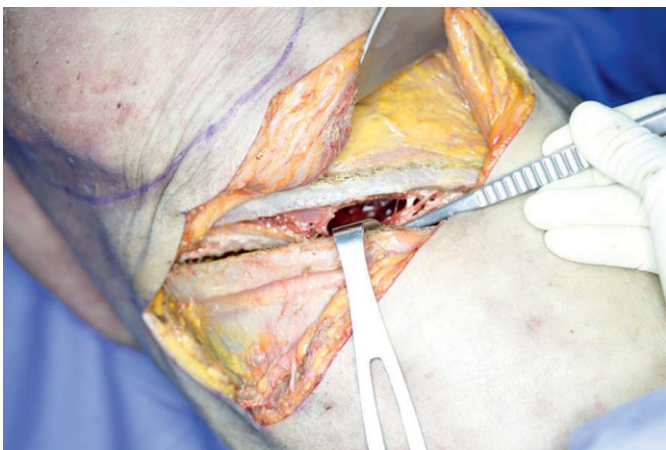


Figure 18.5 Cephalad retraction of the scapula exposes the underlying ribs and intercostal spaces (the tip of the scapula is usually over the sixth or seventh intercostal space).

(a)



(b)



(c)

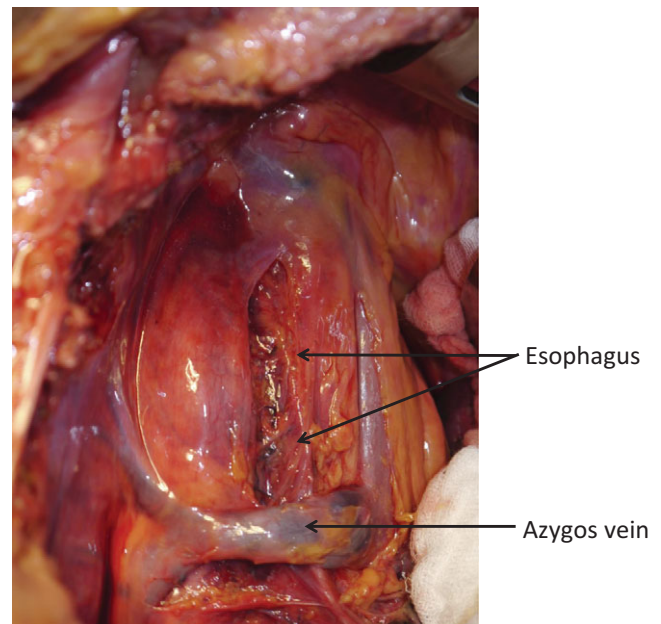


Figure 18.6 (a) Division of the intercostal muscle at its insertion on the superior border of the rib (red arrows) to avoid the neurovascular bundle, which is located at the inferior border of the rib. (b) Blunt dissection of intercostal muscle flap off of the rib. (c) Ligation of the more anterior aspect of the intercostal muscle flap and tag (circle) with heavy silk suture for future use as a buttressed repair.

Exposure of the Thoracic Esophagus

- The upper and middle thoracic esophagus is exposed through a right posterolateral thoracotomy, as described above.
 - Divide the inferior pulmonary ligament and retract the right lung medially.
 - Visualize the mediastinal pleura and inspect for violation or injury. Evacuate debris and devitalized tissue.
 - The azygos vein will be seen coursing across the esophagus toward the superior vena cava.
 - Open the posterior mediastinal pleura overlying the esophagus, along the length of the azygos vein.

(a)



(b)

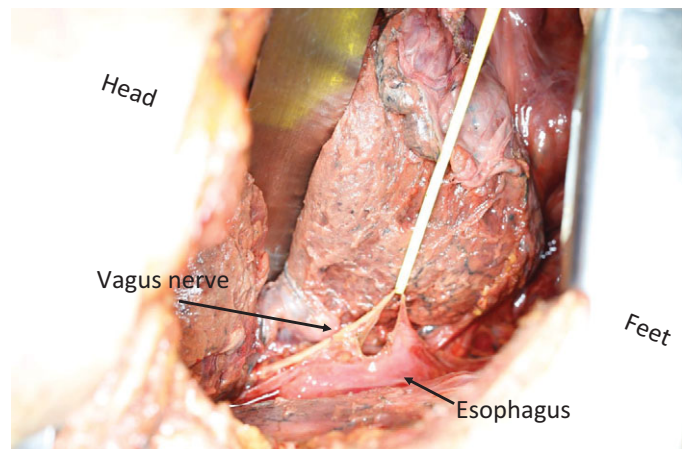


Figure 18.7 (a) Posterior mediastinum with retraction of the right lung anteriorly. The posterior mediastinal pleura overlying the esophagus is incised. The azygos vein, crossing over the esophagus, may be divided. (b) The vagus nerves are identified and protected (left vagus nerve courses anterior as shown, and the right courses posterior).

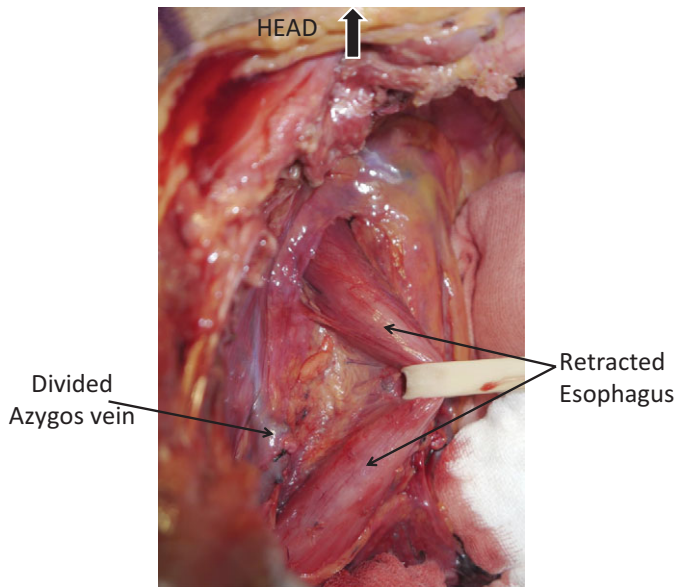


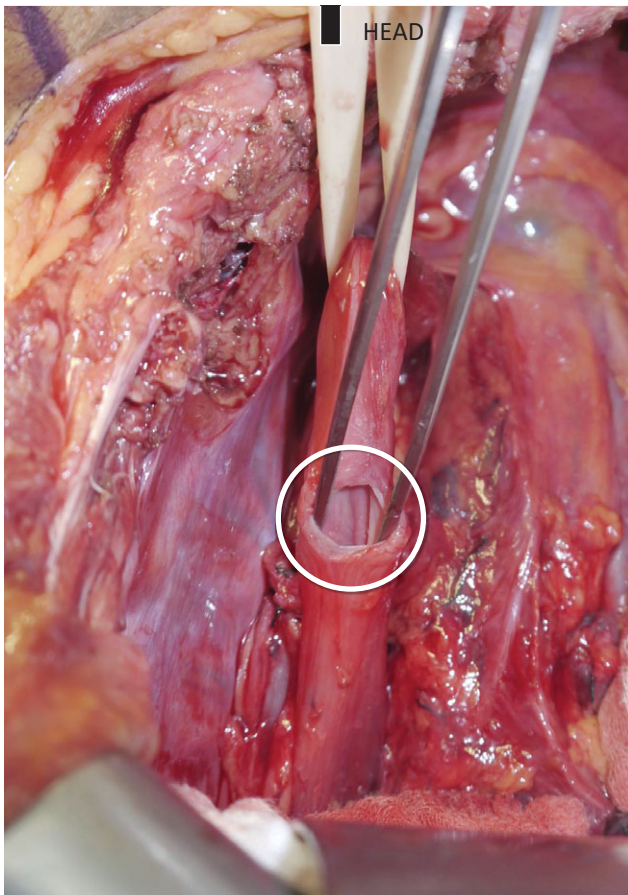
Figure 18.8 The azygos vein is divided, the esophagus is mobilized and a Penrose drain is placed around it for retraction.

- If necessary for exposure, ligate and divide the azygos vein as it crosses the esophagus.
- Mobilize the esophagus and place a Penrose drain around it.
- The lower third of the esophagus is exposed through a left posterolateral thoracotomy, as described above.
 - Divide the inferior pulmonary ligament and retract the left lung medially.
 - The esophagus is located to the right of the thoracic aorta and can easily be palpated after placement of a nasogastric tube.
 - Incise the peritoneum over the esophagus, mobilize and place a Penrose drain around it.

Repair of the Esophagus

- Identify the injury and mobilize the esophagus above and below. Take care not to devitalize the esophagus during mobilization. Open the muscle fibers longitudinally to fully expose the extent of the mucosal injury (Figures 18.9a and 18.9b).

(a)



(b)

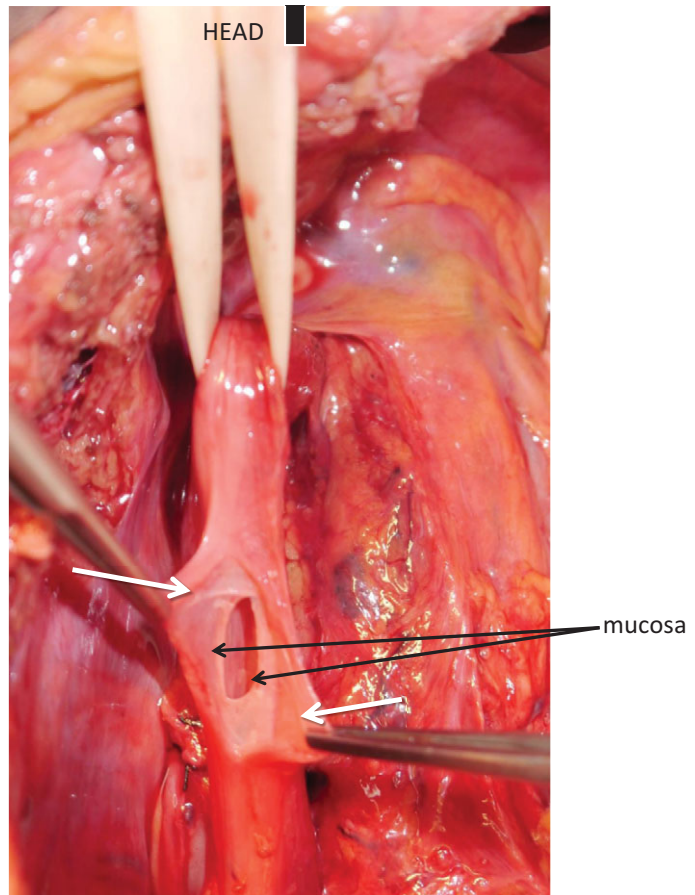
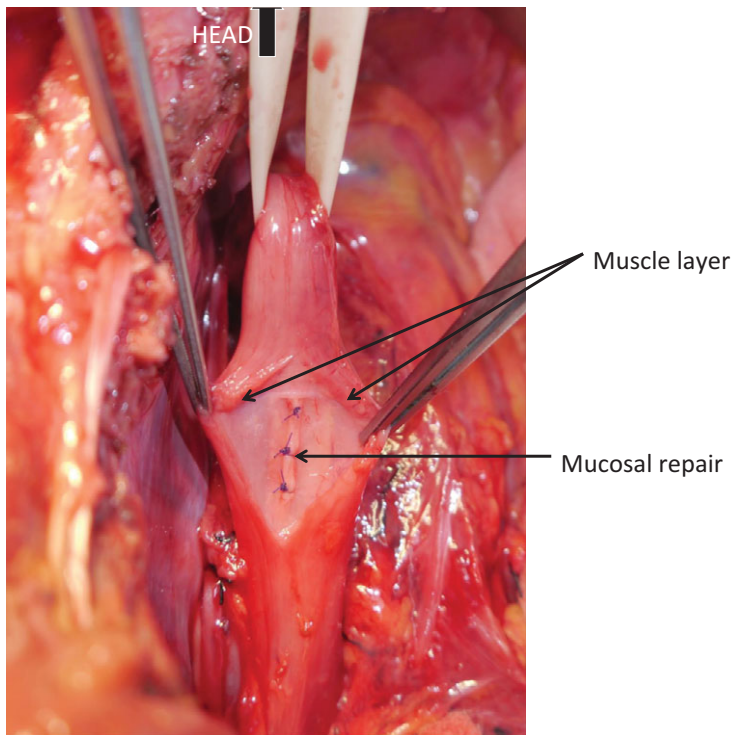


Figure 18.9 (a) Identification of the esophageal perforation (circle). (b) The esophageal muscle fibers (white arrows) are opened longitudinally to fully expose the extent of the mucosal injury (black arrows).

(c)



(d)

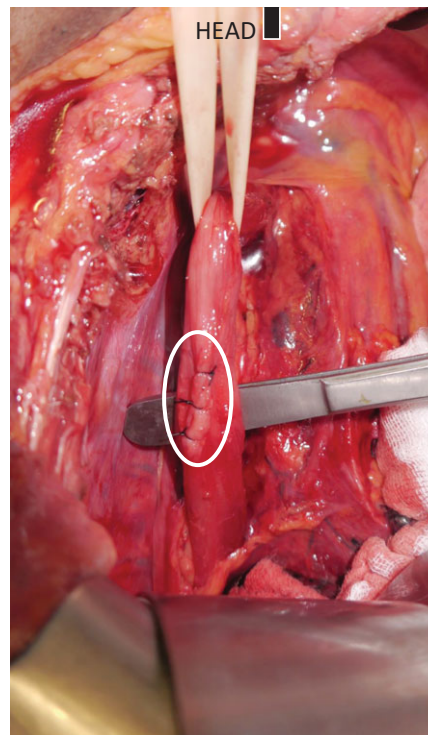


Figure 18.9 (c) The mucosa is repaired with interrupted absorbable suture (white arrows). Muscularis layers are retracted by forceps (black arrows). (d) The muscle layer is repaired with interrupted nonabsorbable sutures (circle).

- Repair the mucosa with interrupted absorbable sutures (Figure 18.9c).
- Repair the muscle layer with interrupted nonabsorbable sutures (Figure 18.9d).
- A flap from the adjacent parietal pleura or a pericardial fat-pad flap or an intercostal muscle flap with its neurovascular bundle may be mobilized and brought over the esophageal repair for additional coverage.

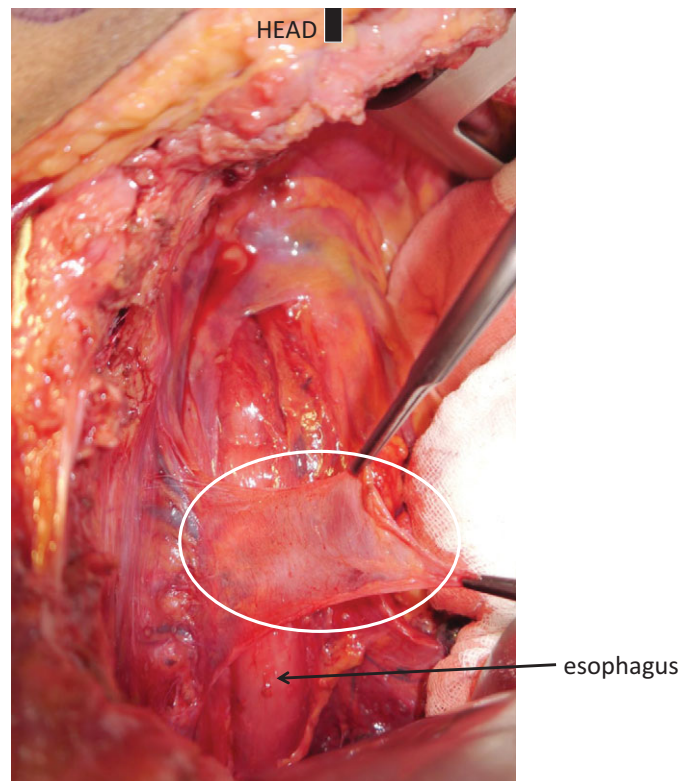


Figure 18.10 A parietal pleura flap (circle) is created and brought over the esophageal repair and sutured in place.

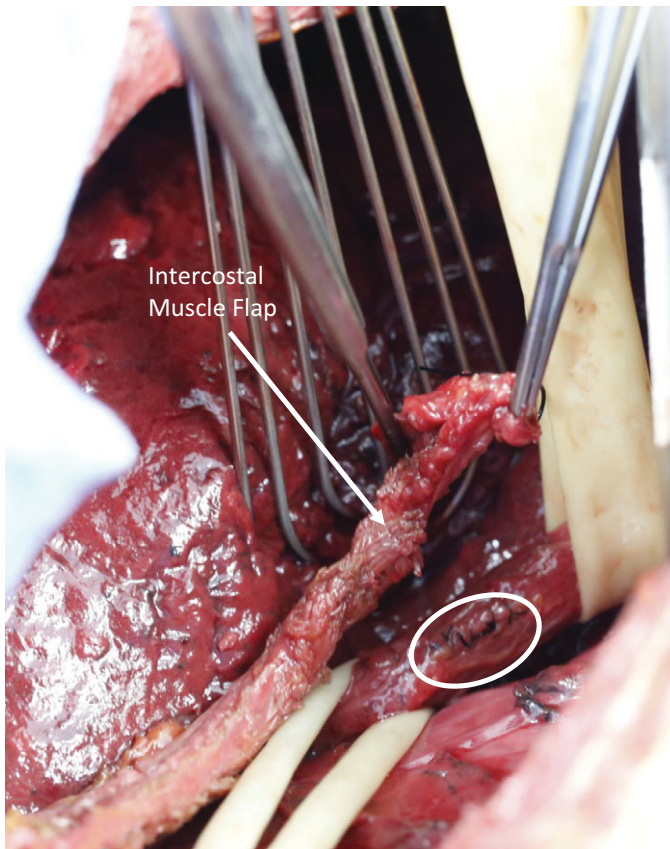


Figure 18.11 An intercostal muscle flap is mobilized and secured with sutures over the esophageal repair (circle).

- The wound is copiously irrigated and drained using standard chest tubes.
- If not placed previously, a nasogastric tube is guided past the site of repair and into the stomach, taking care to avoid damaging the repair site.
- A jejunostomy feeding tube can be inserted through a mini-laparotomy at the time of the esophageal repair.

Exposure and Repair of the Intra-abdominal Esophagus

- A laparotomy is the approach used to repair an injury to the intra-abdominal esophagus.
- The left triangular ligament is divided and the liver is retracted. This exposes the esophageal hiatus.
- The short gastric vessels can be divided to aid with mobilization of the gastroesophageal junction for improved exposure of the injury.
- Following primary repair, the hiatus is closed with interrupted nonabsorbable sutures to recreate an opening that only accommodates the esophagus and one fingertip.
- A feeding jejunostomy tube is placed for postoperative alimentation.
- For destructive injuries, a circular stapled anastomosis placed through a gastrotomy is an acceptable alternative.

Tissue Reinforcement Options

- Pleural flap, intercostal muscle flap, pericardial fat-pad flap

Tips and Pitfalls

- Delayed recognition and repair of the esophagus is associated with a high incidence of septic complications and death.
- Cervical esophageal leaks usually cause an abscess or an esophageal fistula and are rarely life-threatening. However, thoracic esophageal leaks can cause severe mediastinitis and often are life-threatening.
- Any repair or anastomosis should be tension-free and well-perfused.
- Routine wide drainage of all esophageal repairs is critical.
- Use tissue flaps to reinforce the esophageal repair. This is particularly important in the presence of associated tracheal injuries due to the risk of tracheoesophageal fistula or vascular injuries due to the risk of arterioesophageal fistula.

Diaphragm

Lydia Lam and Caroline Park

Surgical Anatomy

- The diaphragm consists of a peripheral muscular segment and central aponeurotic segment. It is attached to the lower sternum, the lower six ribs, and the lumbar spine. During expiration it reaches the level of the nipples. The central tendon of the diaphragm is fused to the base of the pericardium.
- It has three major openings, which include the aortic foramen – which allows passage of the aorta, the azygos vein, and the thoracic duct – the esophageal foramen for the esophagus, and the vagus nerves, and finally the vena cava foramen, which contains the inferior vena cava (Figure 19.1).

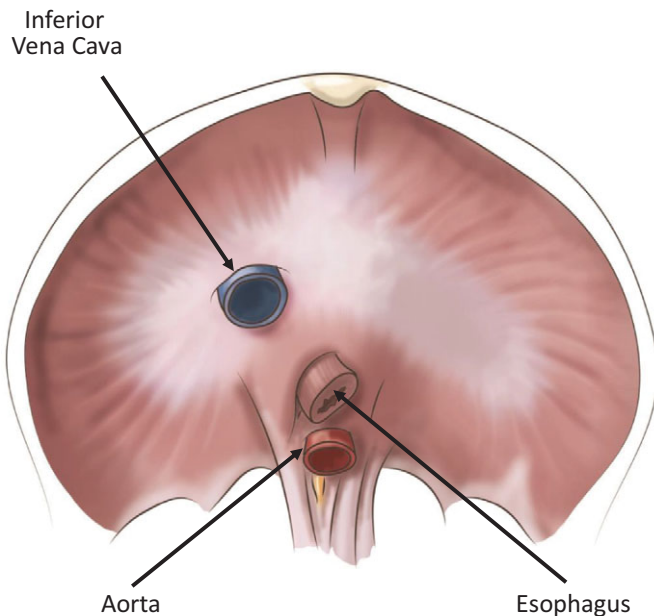


Figure 19.1 Anatomy of the diaphragm and its major foramina.

- The arterial supply stems from the phrenic arteries that are direct branches off of the aorta as it exits the hiatus, while the venous drainage is directly into the inferior vena cava.
- The diaphragm is innervated by the phrenic nerve, which originates from the C3–C5 nerve roots, courses over the anterior scalene muscle, continues into the mediastinum along the pericardium, and terminates in the diaphragm.

General Principles

- The diagnosis of isolated, uncomplicated diaphragmatic injuries can be challenging because they are often asymptomatic and the radiological findings may be subtle or absent.
- Untreated diaphragmatic injuries may result in a diaphragmatic hernia, which can manifest long after the injury (Figure 19.2a and 19.2b).
- Traumatic diaphragmatic hernias occur almost always in the left diaphragm, although in rare cases they may occur in right-sided large diaphragmatic tears due to blunt trauma or small anterior stab wounds.
- The most common herniating viscera include the omentum, stomach, and colon. Less often, the spleen and the small bowel may herniate through an unrepaired diaphragmatic injury.
- A diaphragmatic hernia may cause bowel obstruction or result in ischemic necrosis of the herniating viscus. These conditions are associated with significant morbidity and mortality.
- In penetrating injuries, the diaphragmatic tear is about 3–4 cm. In blunt trauma it is significantly larger, at about 7–8 cm (Figures 19.3a and 19.3b).

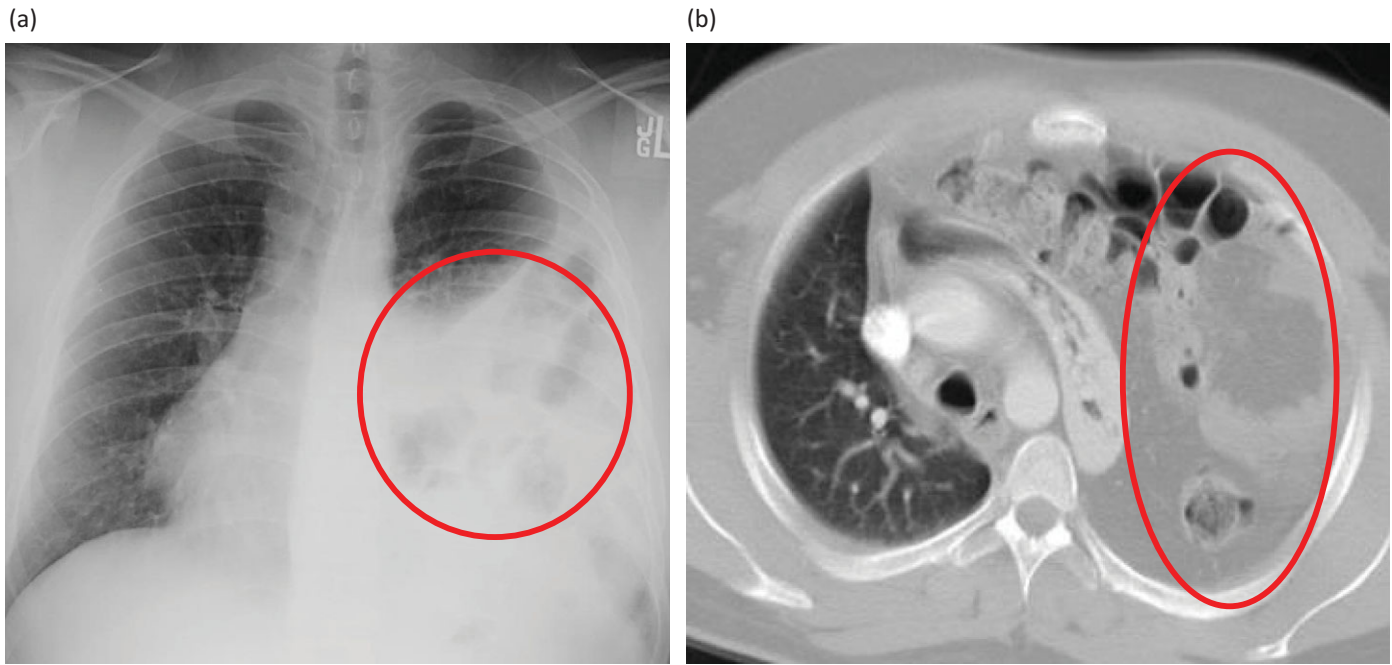


Figure 19.2 (a, b) Left diaphragmatic hernia with stomach and colon in the left chest, following a stab wound to the left thoracoabdominal area many years previously.

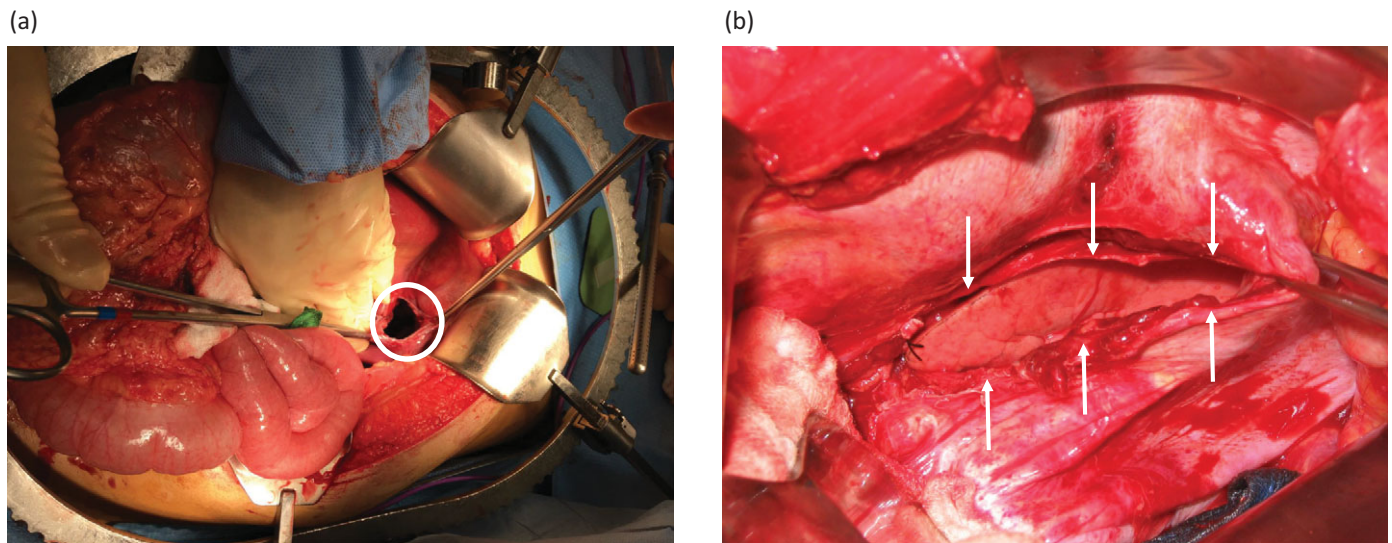


Figure 19.3 (a) Penetrating injury to the left diaphragm (circle). The laceration in penetrating trauma is fairly small, usually about 3–4 cm long. **(b)** Rupture of the left diaphragm due to blunt trauma (arrows). The laceration in blunt trauma is large, usually about 7–8 cm long. Deceleration injuries may cause avulsion of the diaphragm from its attachments.

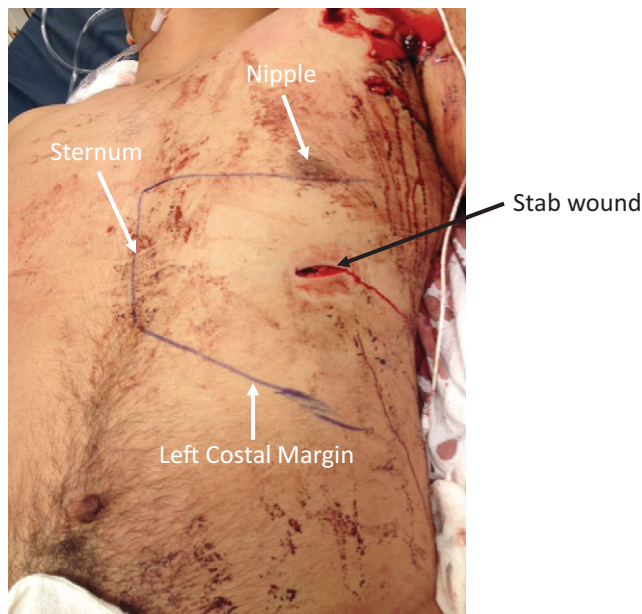


Figure 19.4 All asymptomatic penetrating injuries to the left thoracoabdominal area, between the nipple superiorly and the costal margin inferiorly, should be evaluated laparoscopically to rule out diaphragmatic injury.

- Any asymptomatic penetrating injury to the left thoracoabdominal area, between the nipple superiorly and the costal margin inferiorly, should be evaluated laparoscopically to rule out diaphragmatic injury (Figure 19.4). A normal chest X ray or CT scan do not reliably exclude diaphragmatic injury.
- Patients with hemodynamic instability or signs of peritonitis should undergo an emergency exploratory laparotomy.
- Laparoscopic evaluation and possible repair of diaphragmatic injuries should be considered in asymptomatic patients with left thoracoabdominal penetrating injuries, irrespective of radiological findings. The procedure should be performed at least 6–8 hours after admission, in order to allow any associated hollow viscus injuries to manifest clinically or with leukocytosis.

Special Instruments

- Standard laparoscopic equipment for diagnostic/therapeutic laparoscopy. It should include a 30-degree 10 mm or 5 mm laparoscope, 10 mm or 5 mm trocar for the umbilical port, one 5 mm port for retraction and mobilization, and one 10 mm working port (Figure 19.5).
- Equipment for the open operation would include a major laparotomy tray. A Bookwalter retractor improves the exposure of posterior diaphragmatic injuries.

Laparoscopic Repair

Positioning

- Patient should be placed in the supine and reverse Trendelenburg position with the left side up. The stomach should be decompressed with an orogastric tube.

Trocar Placement

- Trocar placement should adhere to general laparoscopy principals of triangulation to allow access to likely areas of injury on the diaphragm. To begin, a standard periumbilical trocar can be used to insert a camera for diagnostic confirmation of the injury. Once the injury is localized, additional ports can be inserted to maximize access to the injury.
- During insufflation of the abdomen, monitor closely for signs of tension pneumothorax (tachycardia, hypotension, increased peak inspiratory pressures, hypoxia). If there is a suspicion of tension pneumothorax, the abdomen should be deflated immediately and a chest drain should be placed.
- In some cases, it is not possible to maintain the abdominal insufflation pressures because of gas loss through the diaphragmatic defect and into the chest drain. Grasping the edge of the wound with a forceps or clamp and partially twisting it occludes the defect and allows abdominal insufflation.

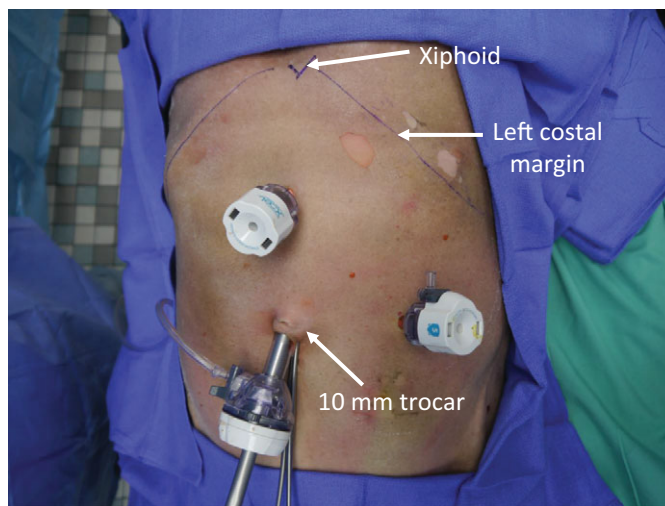
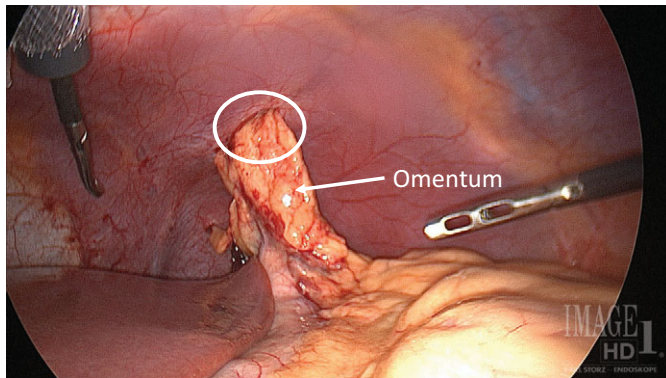


Figure 19.5 Hasson 10 mm trocar is placed just above the umbilicus and is used for the insertion of the scope. Two additional 5 mm ports are placed in the epigastrium and left abdomen. If a diaphragmatic injury is diagnosed and warrants repair, one of the 5 mm ports may be upsized to a 10 mm to allow for passage of a needle.

Repair

- After laparoscopic evaluation of the abdomen for any other associated injuries, any herniating viscus through the diaphragmatic defect is reduced with gentle traction and the extent of the injury is assessed. One of the 5 mm ports is upsized to a 10 mm to allow for passage of a needle with suture (Figures 19.6a and 19.6b).
- Diaphragmatic defects are repaired with interrupted figure-of-eight nonabsorbable sutures, using standard laparoscopic techniques. Alternatively, laparoscopic hernia staples may be used (Figures 19.7a and 19.7b).

(a)



(b)

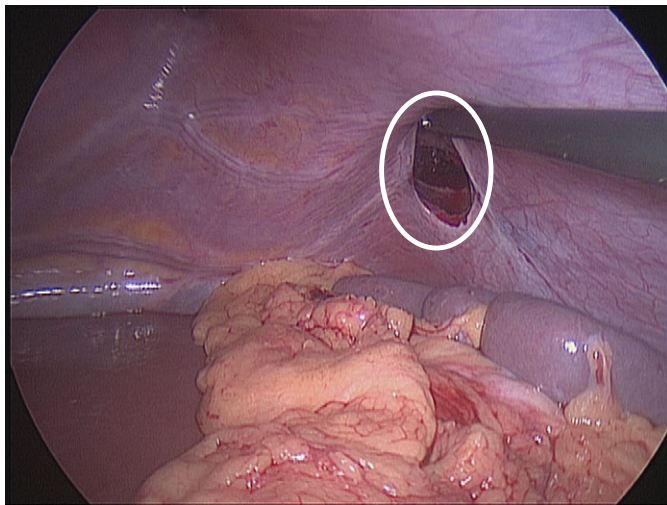
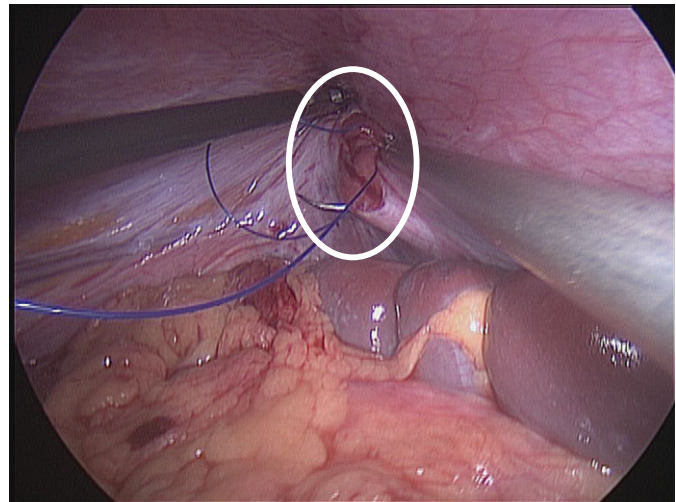


Figure 19.6 (a) Laparoscopic appearance of a left diaphragmatic injury (circle) with omentum herniating through the defect (arrow). (b) Diaphragmatic defect after reduction of the herniating omentum.

(a)



(b)

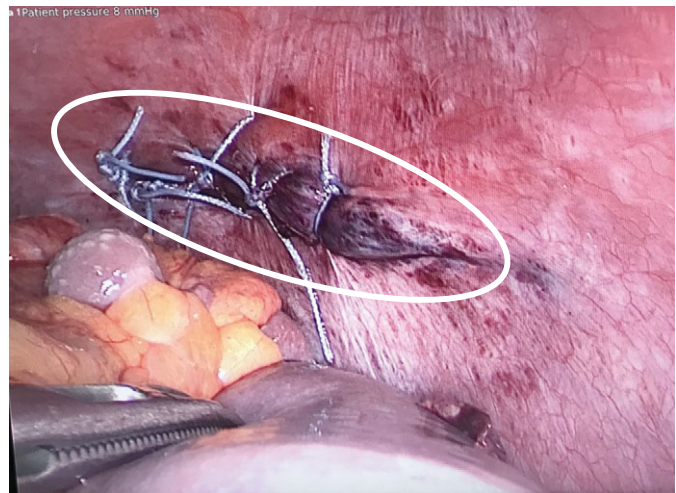


Figure 19.7 (a and b) Laparoscopic repair of left diaphragmatic defect with figure-of-eight sutures.

Open Repair

Positioning

- Patient should be placed in the supine position with both arms abducted.
- A standard trauma preparation from the chin to the knees is used as access to the chest for a thoracostomy tube insertion may be necessary.

Incision

- A standard upper midline laparotomy incision starting at the xiphoid and long enough to allow a complete exploration of the abdomen.
- A thoracotomy should never be used for acute repair of a diaphragmatic injury because it does not allow exploration for associated intra-abdominal injuries or resection of ischemic viscera in cases with an incarcerated hernia and gangrenous stomach or intestine.
- For chronic diaphragmatic hernias, a thoracic approach may be considered. The choice of thoracotomy versus laparotomy is a matter of personal preference.

Exposure

- The patient is placed in the reversed Trendelenburg position and the operating table is turned slightly to the patient's right side to improve exposure of the left diaphragm.
- Superior caudal retraction of the costal margins is key to adequate exposure of the diaphragm. The use of a fixed retractor, such as the Bookwalter retractor, is strongly recommended.
- For posterior diaphragm injuries, the exposure can be improved by medial rotation of the spleen.
- The diaphragmatic wound edges are grasped with Allis clamps and pulled anteriorly and downwards, to improve exposure and repair. Clamps can be placed at the apices to line up the edges of the laceration and facilitate suturing. This is particularly important for posterior injuries, which are difficult to access (Figure 19.8).

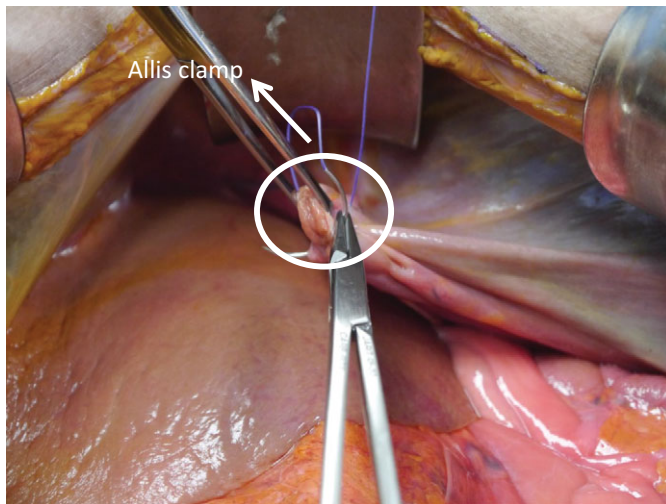


Figure 19.8 An Allis or Kocher forceps is placed to the diaphragmatic defect and traction is applied to deliver the diaphragmatic injury into the surgical field and make the repair easy.

- If there is a diaphragmatic hernia, reduce the contents with gentle traction. If necessary, enlarge the diaphragmatic defect to reduce incarcerated contents. Inspect contents for any ischemic necrosis.

Repair

- Before diaphragmatic repair, a suction catheter is inserted through the defect into the thoracic cavity and any associated hemothorax is suctioned out. If there is an associated hollow viscus injury with contamination, copious irrigation and suctioning of the pleural cavity should be performed.
- The diaphragmatic injury is pulled with an Allis or Kocher clamp into the surgical field, as described above.
- The diaphragmatic defect is repaired with interrupted figure-of-eight sutures, using number 0 or 1 monofilament, nonabsorbable sutures (Figure 19.9).
- High-energy deceleration injuries can result in avulsion of the diaphragm from its chest wall attachments. In these instances, the diaphragm will need to be secured to the chest wall. It may be necessary to perform a thoracotomy to allow horizontal mattress sutures to be placed around the ribs to secure the diaphragm in its normal position. The use of synthetic meshes is rarely necessary in the acute setting as tissue loss and domain loss have not had time to occur.
- A tube thoracostomy should always be placed after the diaphragm repair.

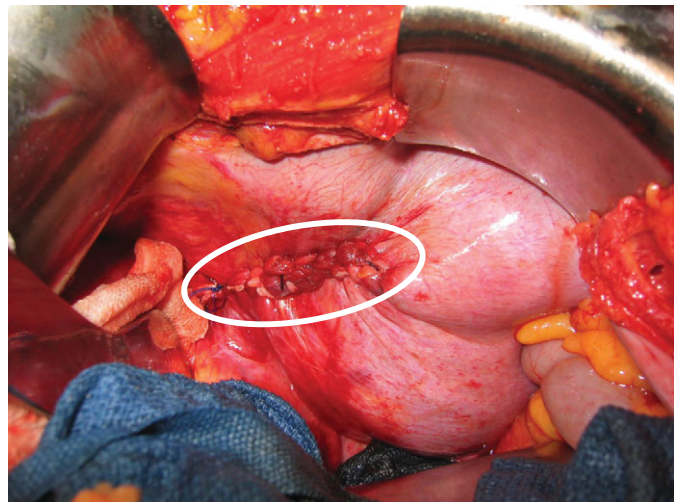


Figure 19.9 Repair of a large left diaphragmatic injury following blunt trauma.

Tips and Pitfalls

- In the presence of a diaphragmatic defect, there is a risk of tension pneumothorax during abdominal insufflation for laparoscopy. Monitor closely the hemodynamic and oxygenation status and peak inspiratory pressures. If any sign of tension pneumothorax develops, release the abdominal insufflation and make sure that a chest drain is in place or inserted.
- In some cases, laparoscopic repair may be difficult because of the loss of the insufflation pressure through the diaphragmatic defect and into the chest drain. Grasping the edge of the wound with forceps or clamp and partially twisting it can occlude the defect and allow repair.
- Repair of posterior diaphragmatic wounds during laparotomy is difficult due to poor exposure. Improve exposure by placing the patient in the reverse Trendelenburg position, and rotate the spleen medially. Grasp the edges of the wound with Allis or Kocher forceps and pull the diaphragm towards the laparotomy incision.
- In the presence of peritoneal intestinal content contamination, there is an increased risk of empyema. Wash out the pleural cavity through the diaphragmatic defect and remove any gross contamination.
- Although rare, during repair of the diaphragm below the pericardium, place the sutures under direct visualization to avoid inadvertent injury to the myocardium.
- After diaphragmatic repair, always place a thoracostomy tube for postoperative drainage.

Surgical Fixation of Rib Fractures

Travis M. Polk and Paul Wisniewski

Surgical Anatomy

- Anatomy of the ribs. There are 12 ribs on each side. All 12 connect posteriorly with the vertebrae of the spine. Ribs 1–7 connect anteriorly directly to the sternum, while ribs 8–10 attach to the superior costal cartilages. Ribs 11 and 12 are floating ribs with no anterior attachment. The intercostal vein, artery, and nerve run in the costal groove, which is located along the inferior border of each rib.
- Anterior chest wall
 - Pectoralis major muscle: The origin is the anterior surface of the medial half of the clavicle and the anterior surface of the sternum. It inserts into the upper humerus. The blood supply is the pectoral branch of the thoracoacromial trunk.
 - Pectoralis minor muscle: The origin of the muscle is on the third through fifth ribs near their cartilages. It inserts into the coracoid process of the scapula.
- Lateral chest wall
 - Serratus anterior muscle: The origin is the lateral part of the first 8–9 ribs. It inserts into the medial aspect of the scapula.
- Posterior chest wall
 - Latissimus dorsi muscle: The origin is the spinous processes of the lower thoracic spine and posterior iliac crest. It inserts into the upper portion of the humerus.
 - Trapezius muscle: The origin of the trapezius muscle is large, from the occipital bone down through the spinous processes of T12. It inserts on the lateral third of the clavicle and the scapula.
 - Erector spinae muscle: The origin is the spinous processes of T9–T12 vertebrae and the medial slope of the iliac crest.
 - Access to fractures underlying the scapula is obtained through the “auscultatory triangle” between the

superior edge of the latissimus dorsi, the lateral border of the trapezius, and the inferomedial border of scapula.

General Principles

- The goal of operative rib fixation is to stabilize the chest wall to improve the mechanics of breathing and reduce pain. The procedure should be considered in selected cases with large flail segments, especially in patients who are difficult to wean off the ventilator.
 - Early fixation within the first few days of hospitalization is considered optimal.
- Operative rib fixation for flail chest may shorten duration of mechanical ventilation, ICU length of stay, hospital length of stay, incidence of pneumonia, and need for tracheostomy.
- During operative fixation, rib fractures that are significantly displaced should be fixated. The nondisplaced, less severe side of a flail can often be left alone if the chest wall is stable. Ribs 1–3 rarely require fixation, since they are both more stable and more difficult to access.
- Video-assisted thoracoscopy (VATS) is often utilized concurrently to facilitate evacuation of residual hemothorax, ensure full inflation of the lung, and inspect the diaphragm, although some prefer to simply enter the pleural space for open irrigation. In all cases, a chest tube is left for pleural decompression at an alternative site.
- Preoperative bronchoscopy can ensure clearance of secretions and facilitate bacterial testing. If positive for bacteria, antibiotics should be administered to prevent infection of the hardware to be inserted.
- A high-resolution chest CT with three-dimensional reconstruction should be obtained for preoperative planning. This allows an assessment of the degree of displacement of the various fractures and planned approach.

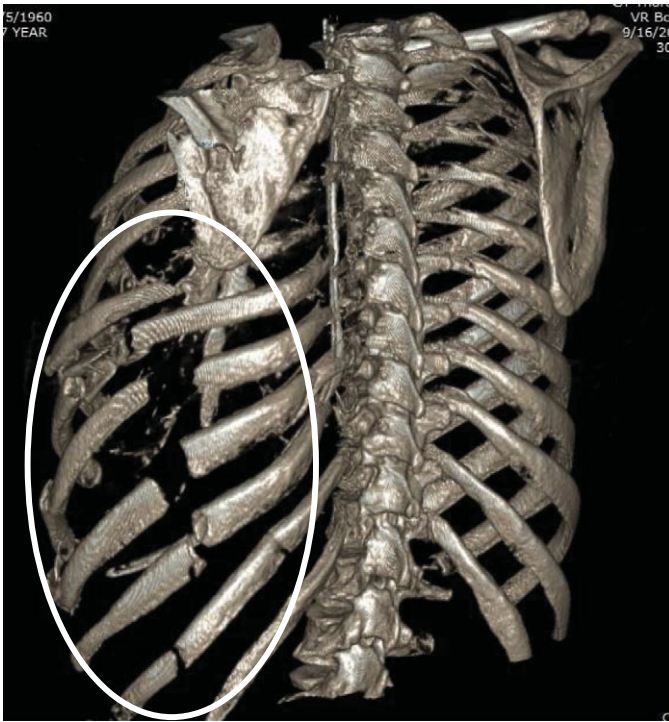


Figure 20.1 3D computed tomography reconstruction demonstrating a flail chest segment with multiple double rib fractures (circle).

- There are many different fixation systems, and most use metal plates with locking screws. Titanium plating with cortical screws (single plate or U-type plate) or absorbable plates are the most commonly used commercial devices by trauma surgeons. Each system has a different system of rib fixation, and the instructions should be read carefully. The system used for this chapter utilizes 2.3 mm × 7 mm drill-free locking screws for unicortical fixation of titanium rib plates.

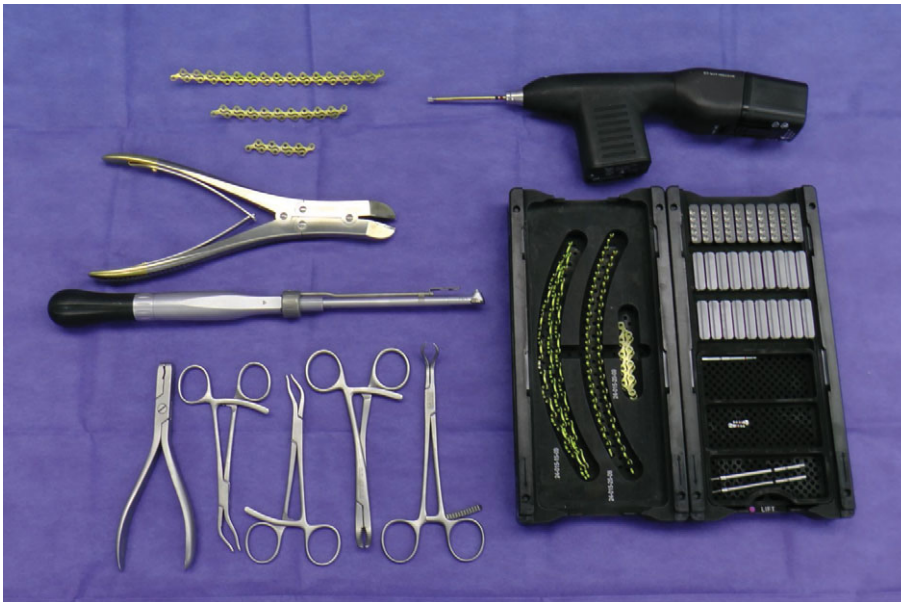


Figure 20.2 Rib plating system. Key equipment (clockwise from top): Shaped rib plates; power screw driver; screws and plates; rib reduction clamps; rib plate clamps; plate bender; right-angle screwdriver; and plate cutter. There are many commercially available rib plating systems, and the surgeon should read carefully the instructions for each system.

Special Instruments

- Chest instrument set
- Rib fixation system
- Thoracostomy tube
- Optional: VATS equipment

Patient Positioning

- Optimal positioning depends upon the ribs targeted for fixation and the chosen approach.
 - Anterior: supine with arms abducted at 90°. Alternatively, the arms can be suspended in stirrups.
 - Lateral: Lateral decubitus position. A bean bag can be used for additional support, with an axillary roll. The hips should be secured with a large adhesive tape or strap. The top leg will remain straight and the bottom leg flexed at the knee with appropriate padding between the legs. The top arm is extended forward and upward, secured on a padded arm holder. Care must be taken to avoid overextension of the arm to prevent a brachial nerve injury.
 - Posterior: Prone with affected arm hanging off bed in supported fashion. The arm should be supported on a mayo stand or stool at a lower level than the operative bed. This helps mobilize and elevate the scapula to improve exposure.

Surgical Technique

- The three general approaches to rib fixation include anterior/inframammary, posterolateral, and posterior. The decision to choose one over the other depends on the location of the fractures. Ideally, the incision should be made either directly over the fracture or myocutaneous flaps can be easily mobilized to expose segments of multiple fractures. The anterior approach is performed in the supine position, while the posterolateral approach is typically performed through a lateral decubitus position. Alternatively, some approach the posterior ribs from a prone position. While lateral decubitus positioning may afford access to a larger area of the chest wall for fracture

fixation, the prone and supine positions have the advantage of allowing access to both sides of the chest without repositioning.

- Anterior / Inframammary
 - Incision: Similar approach to standard anterolateral thoracotomy. The incision should be made over the fractures to be repaired along the line from the sternum, with an inframammary incision that extends superior laterally towards the posterior axilla.
 - Dissection involves mobilization of the pectoralis major muscle posteriorly to access the underlying rib surfaces.
 - The serratus anterior and pectoralis minor muscles are then split and cleared to expose the fractured ribs to be plated.



Figure 20.3 Anterior/inframammary approach utilizes a similar incision to an anterolateral thoracotomy. It starts at the parasternal border, follows the curve of the ribs aiming toward the apex of the axilla, and ends at the posterior axillary line. The I level of the incision is adjusted depending upon the level of ribs targeted.

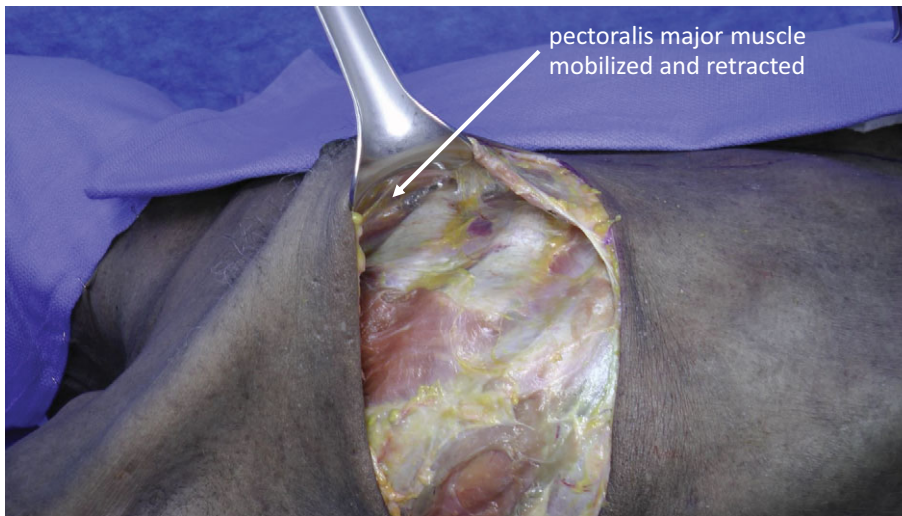


Figure 20.4 The pectoralis major muscle is mobilized posteriorly off the anterior chest wall to expose the underlying ribs.

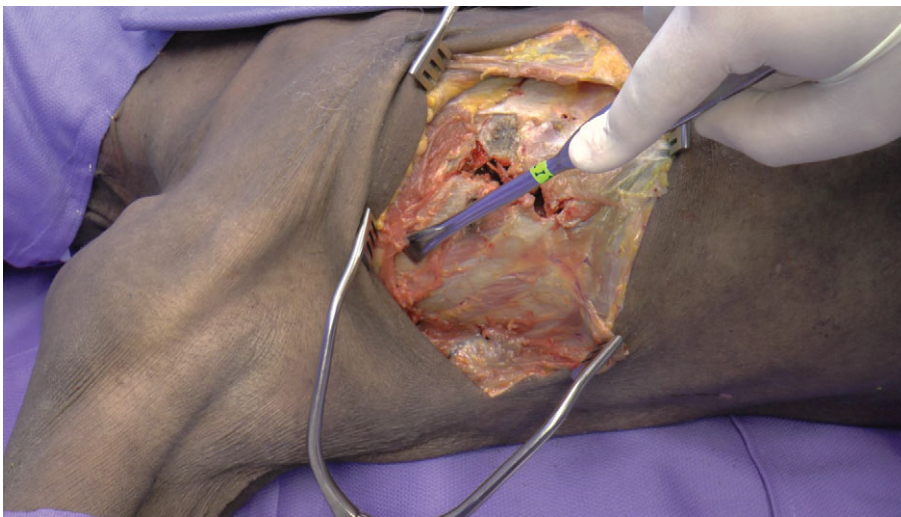


Figure 20.5 After mobilization of the pectoralis major muscle, the serratus anterior fibers must be cleared from the underlying ribs to be plated.

- Posterolateral
 - Incision and approach is similar to the posterolateral thoracotomy (see [Chapter 4](#) for detailed description of surgical approach).
- Posterior
 - Incision is either curvilinear around the scapula or paraspinal to reach more ribs.
 - Dissection begins with mobilization of the lateral edge of the trapezius and upper border of the latissimus until the infrascapular space is entered through the “auscultatory” triangle.
 - The scapula can be elevated to access the posterior upper ribs. Division or splitting of the underlying serratus anterior musculature and medial mobilization of the erector spinae is often necessary for exposure.

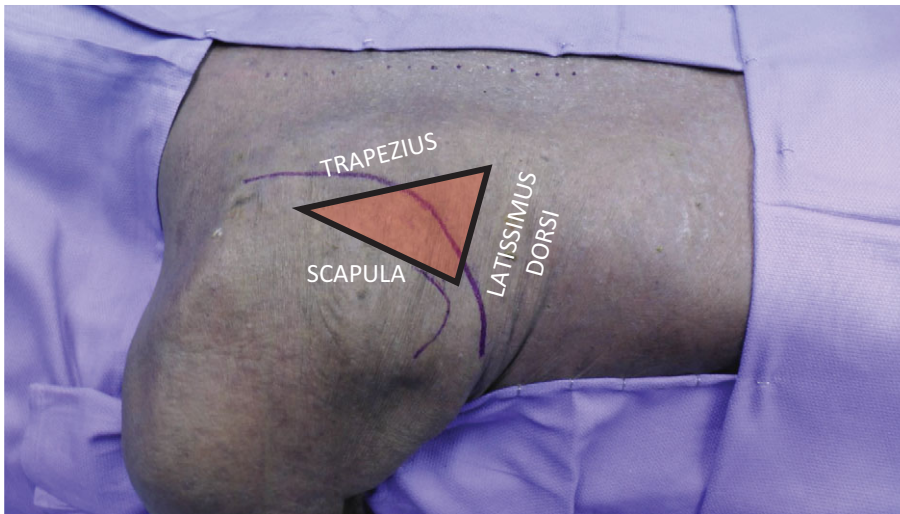


Figure 20.6 The posterior upper ribs can be exposed through a curvilinear incision around the scapula and extending laterally. The subscapular space is accessed through the “auscultatory triangle” (red triangle).

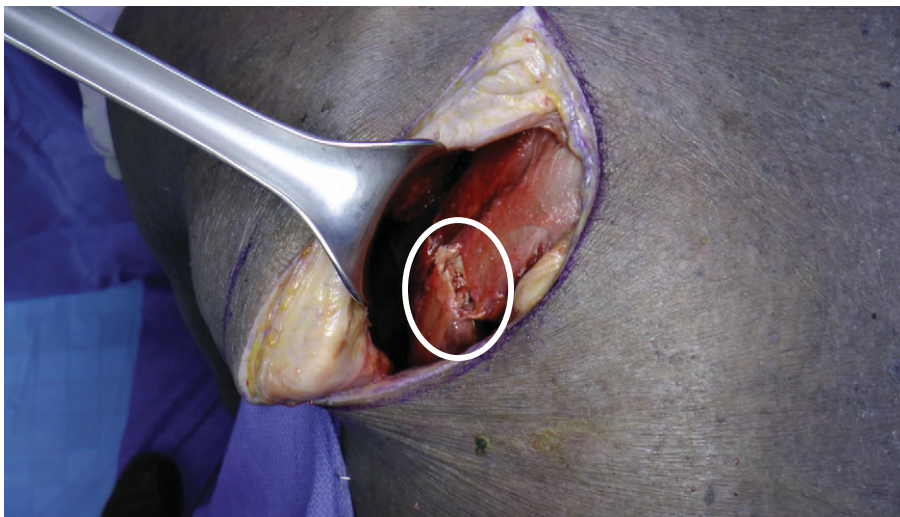


Figure 20.7 The scapula is elevated exposing an underlying rib fracture (circle).

- The remainder of the procedure follows the same general principles regardless of approach.
 - Exposure must be adequate to visualize and reduce the fracture and allow an appropriately sized landing zone for the plate and cortical screws.
- Rib fractures are reduced, and the rib segments aligned using reduction clamps, while ensuring “bone on bone” contact for optimal healing.

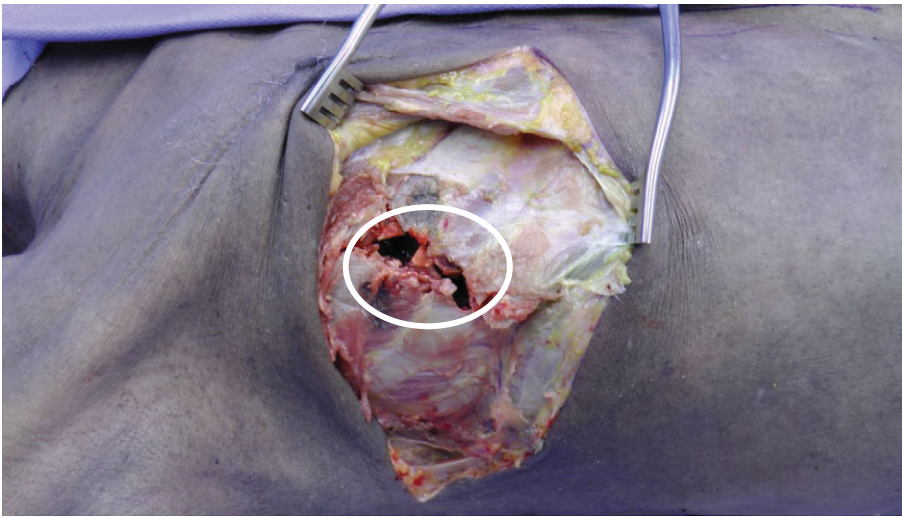


Figure 20.8 Anterolateral approach. Fractures of the fifth and sixth ribs (circle) are seen following mobilization of the pectoralis major muscle.

(a)

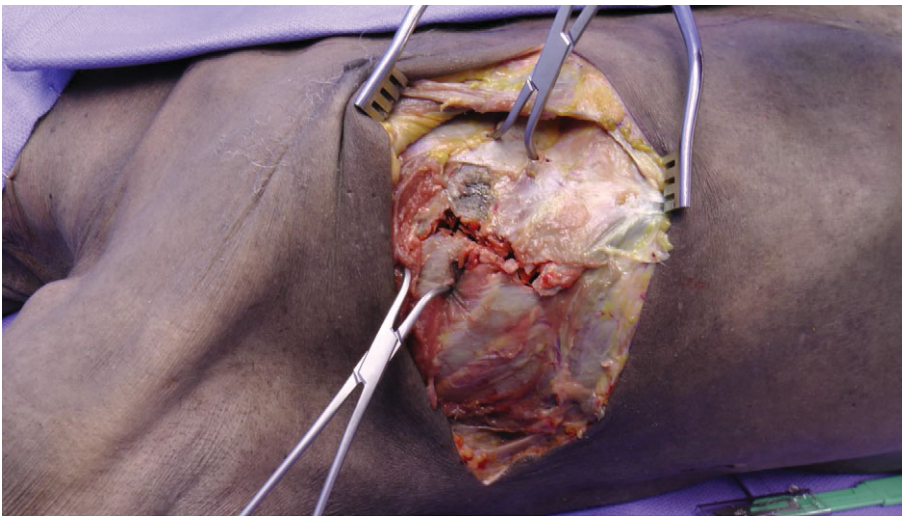
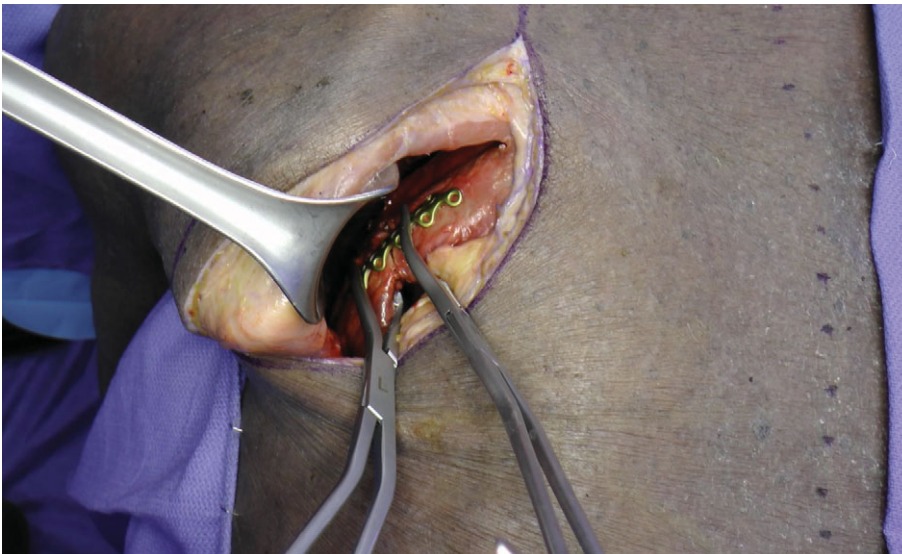


Figure 20.9 Reduction clamps are utilized to mobilize the ribs and achieve fracture alignment. Anterior fracture view (a); Posterior fracture reduction using longer angled clamps (b).

(b)



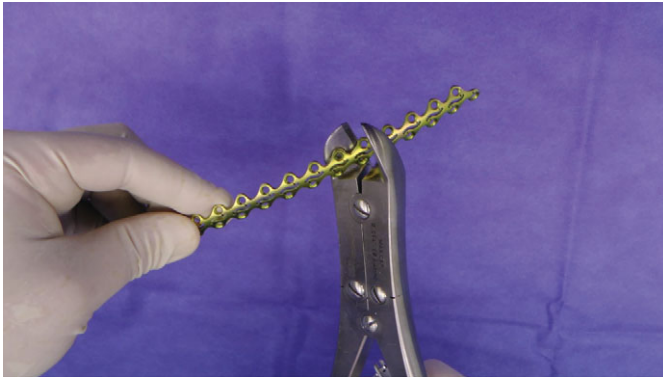


Figure 20.10 Plates are cut to the appropriate size to fit the wound using heavy shears.



Figure 20.11 Plates are to be bent to fit the curvature of the rib being plated.

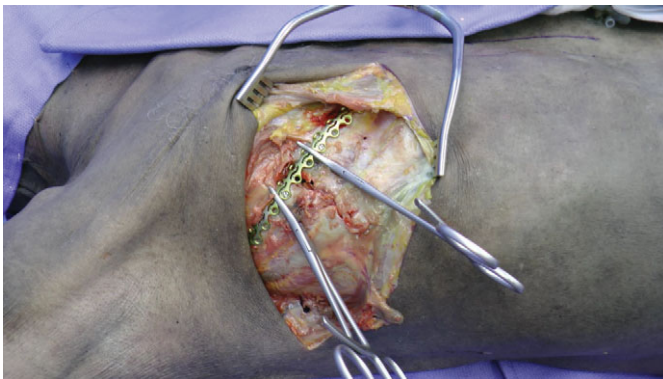


Figure 20.12 Plate clamps secure plates to rib and maintain fracture reduction.

- Rib fixation plates should be trimmed and shaped as necessary to fit the wound size and the curvature of the chest wall prior to application.
- Plates are secured flush to the underlying fracture site with clamps.

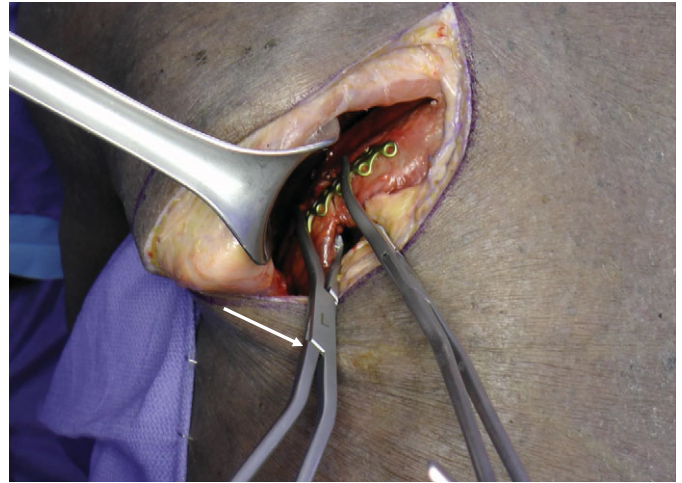


Figure 20.13 Longer angled plate clamps (arrow) can be utilized for posterior or difficult locations.

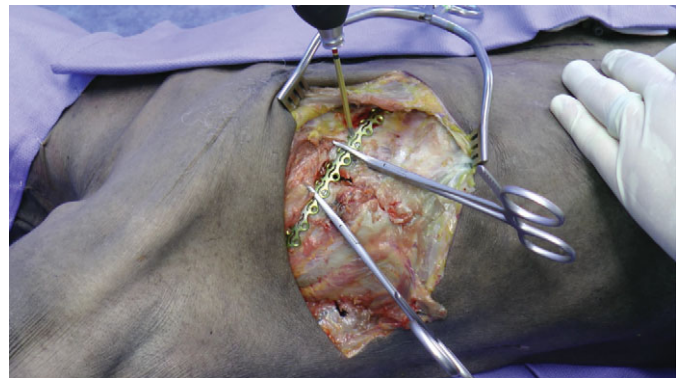


Figure 20.14 A power screw driver is used to place self-drilling locking unicortical screws.

- Cortical screws are then placed using hand or power screwdriver. All screws should be hand tightened to ensure that they are fully engaged and locked. A right-angle screwdriver can be utilized for difficult-to-reach locations. Although not illustrated, some rib fixation systems will require depth measuring and predrilling for screw placement.

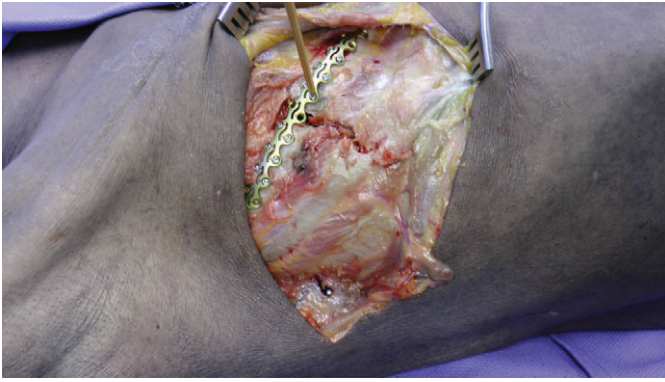


Figure 20.15 Each screw is hand tightened to ensure locking into place.



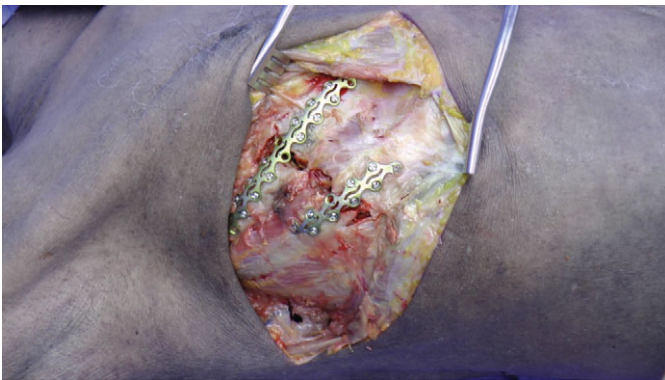
Figure 20.16 A right-angle screwdriver is used under the scapula or in other difficult locations.

- Any previously divided muscle should be closed with absorbable suture. This provides well-vascularized, healthy soft tissue coverage of the hardware to avoid pressure necrosis. The wound is irrigated and closed in layers.
- Entrance into the pleura often occurs during rib plating. A tube thoracostomy is good practice if there is any concern of pleural violation or iatrogenic lung injury.

Tips and Pitfalls

- A muscle sparing technique is preferable to avoid dysfunction of the chest wall and postoperative pain. Regardless of the approach, muscle sparing is usually achievable.
- Anterior and posterior rib fractures are difficult to fixate. For extremely anterior rib fractures, fixation to the sternum is preferable over fixation to costal cartilage. Posterior fractures must have at least 3–5 cm posteriorly for plate fixation to be effective.
- Intrapleural fixation via VATS may be considered for all rib fractures and possibly easier in very posterior rib fractures. This requires contouring the plates in the reverse direction.
- If the plates are not well affixed to the ribs and have not been “locked down,” then you must reverse the screws and re-clamp the plate so that the screws can fully engage the cortical bone and hold the plate in place securely.

(a)



(b)

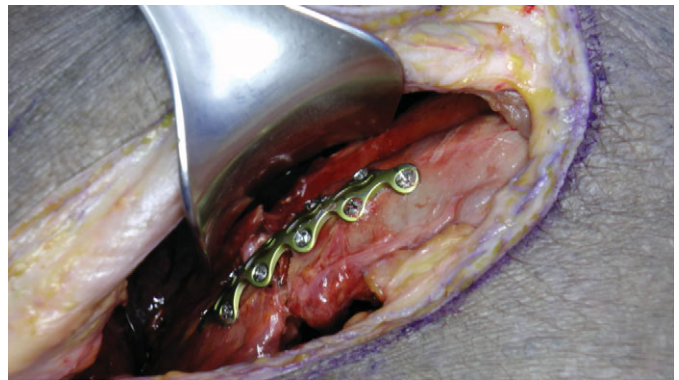


Figure 20.17 Completed rib fixation of (a) anterior sixth and seventh rib fractures. (b) Posterior subscapular rib fracture.

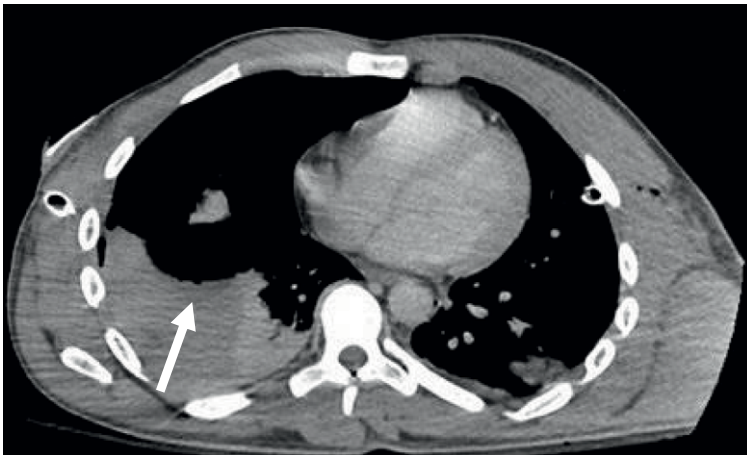
Video-Assisted Thoracoscopic Evacuation of Retained Hemothorax

Aaron Strumwasser and Matthew J. Forestiere

General Principles

- The majority of traumatic hemothoraces can be managed successfully with a chest tube placement.
 - Retained hemothorax is defined as residual pleural blood >300–500 mL after initial thoracostomy tube evacuation.
 - The gold standard for diagnosing retained hemothorax is a noncontrast CT scan of the chest. A chest X-ray is not reliable in the accurate diagnosis of retained hemothorax.
 - VATS is usually contraindicated in patients with previous thoracic operations and in patients with respiratory failure
- or significant contralateral lung injury, such as contusion, atelectasis, or pneumonia, because single-lung ventilation may not be tolerated.
- Ideally, VATS should be done within the first 3–5 days. Early VATS (within 72 hours of admission) for evacuation of retained hemothorax reduces hospital length of stay, number of procedures, and cost. VATS is more difficult and less effective if performed more than 7–10 days after the injury, due to clot organization and dense adhesions.

(a)



(b)

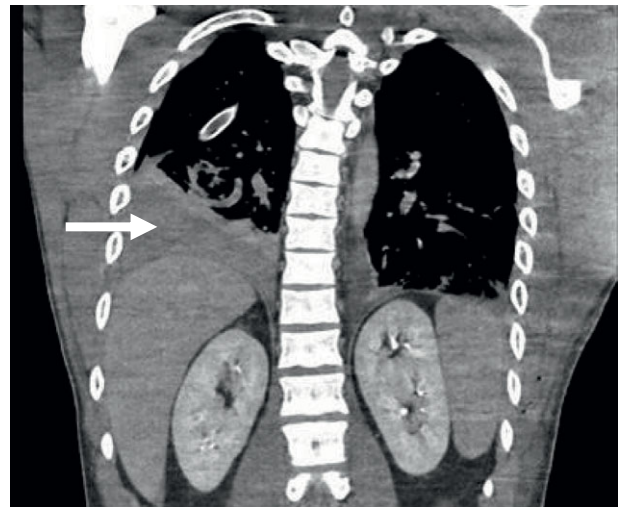


Figure 21.1 (a, b) CT images of right retained hemothorax (white arrows).

Patient Preparation and Positioning

- After intubation with a double-lumen endotracheal tube, the patient is placed in lateral decubitus position (operative thorax up) on a vacuum bean bag. The hips are secured to the table with wide adhesive tape.
- If there is no spinal injury, the operating room table should be flexed at the hips to increase the separation of the ribs, and reduce the risk of trauma to the intercostal nerves and chronic postoperative pain.
- The dependent arm is extended on the operating table for ease of access for anesthesia. The superior arm is extended

and flexed at the elbow and secured on an arm board. The elbow should extend cephalad to rest above the shoulder so as to not interfere with the surgeon.

- The lower leg is bent and the upper leg left straight, with a pillow between the knees. All bony prominences and axilla (brachial plexus) should be well padded to prevent neuropraxia to the brachial plexus and peroneal nerves (most common nerve injuries).
- In the lateral decubitus position, the external landmarks to note for port insertion planning include: the tip of the scapula and mid and anterior axillary lines.

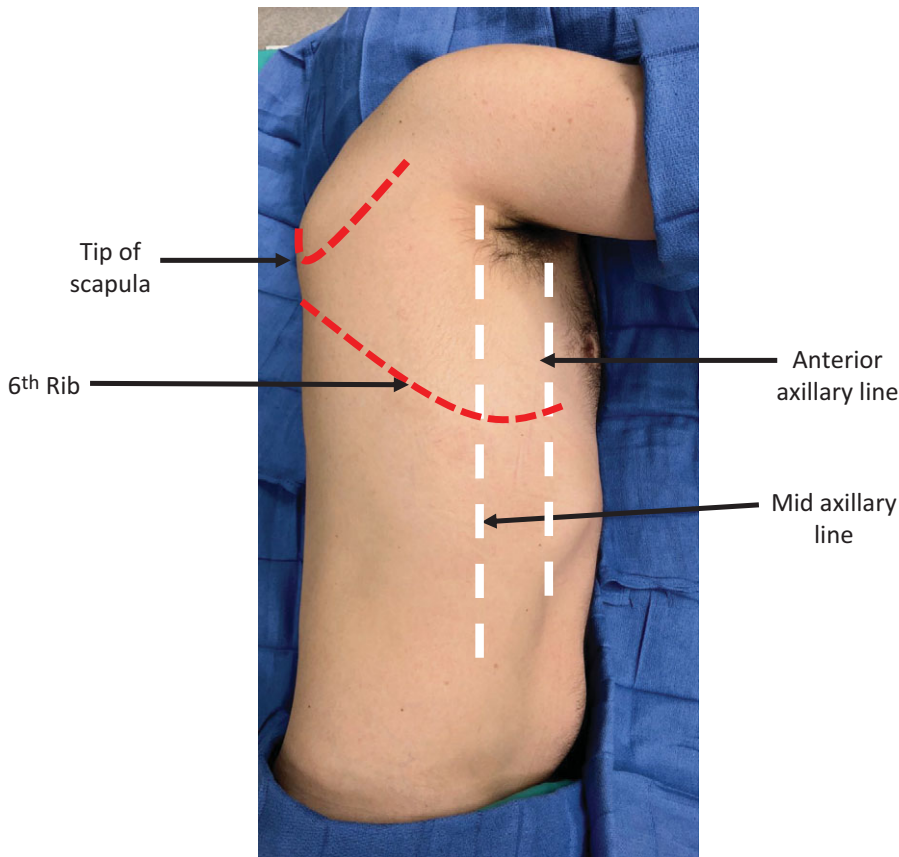


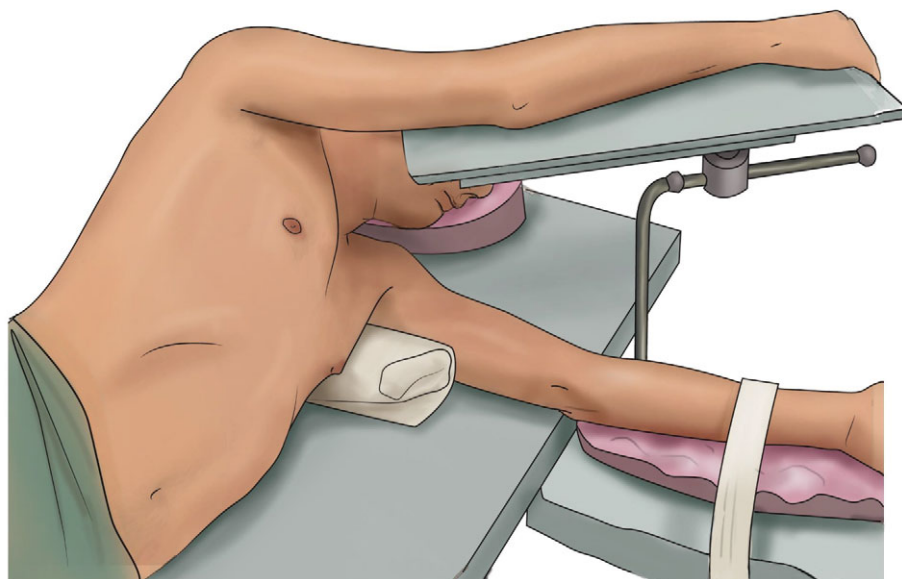
Figure 21.2 In the lateral decubitus position, the external landmarks to note for port insertion planning include: the tip of the scapula, and mid and anterior axillary lines.

(a)



Figure 21.3 (a) Standard VATS positioning. Care must be taken to appropriately pad both arms to avoid iatrogenic musculoskeletal or neurological injury. Jack-knifed position opens the lower rib spaces to allow for ease of trocar entry and use. (b) The dependent arm is extended on the operating table for ease of access for anesthesia. The superior arm is extended and flexed at the elbow and secured on an arm board. The elbow should extend cephalad to rest above the shoulder so as to not interfere with the surgeon.

(b)



Equipment

- Basic instruments needed:
 - Articulating thoracoscope (5 mm or 10 mm, 0° or 10°)
 - 10 mm short metal tracer
 - Long and short curved ring forceps
 - Long and short Harken clamps
 - Long Metzenbaum scissors
 - Sponge stick on ring forceps
 - Kittner or Peanut
 - Endoscopic stapler (if planning on resection)
 - Open thoracotomy tray
 - A power irrigator with suction may be used to break up clots and peel of pseudomembranes from around the lung and the parietal pleura
 - Standard thoracostomy tubes



Figure 21.4 Typical instrumentation needed for video-assisted thoracoscopic surgery. For the camera, an angled or articulating video 10 mm thoracoscopic scope is ideal. For instruments, a 10 mm short metal or VATS trocar, long and short curved ring forceps, long and short Harken clamps, long Metzenbaum scissors, Army Navy retractors, Weitlaner retractors, sponge stick on a ring forceps, a Kittner or peanut, and a power suction irrigator.

Surgical Technique

- A double-lumen tube (or mainstem intubation of single-lumen tube) is placed by the anesthesiologist, and the lung is deflated on the side of the working hemithorax.
- Operating surgeon stands on the anterior side of the thorax, with the assistant standing on the posterior side of the thorax.
- The number and sites of ports should be determined by the location of the hemothorax. In most patients that have basolateral or posterolateral residual hemothorax usually only three ports, forming an isosceles triangle, are needed. The initial port is 10 mm to accommodate the thoracoscope and is generally placed around the sixth to seventh intercostal space along the mid/posterior axillary line. The second working port is generally placed superiorly in the fifth to sixth intercostal space along the anterior axillary line to allow good visualization of the base. A third port is placed either in the posterior axillary line in the sixth to seventh intercostal space. In thin patients, instruments may be introduced directly through incisions, without the help of trocars.

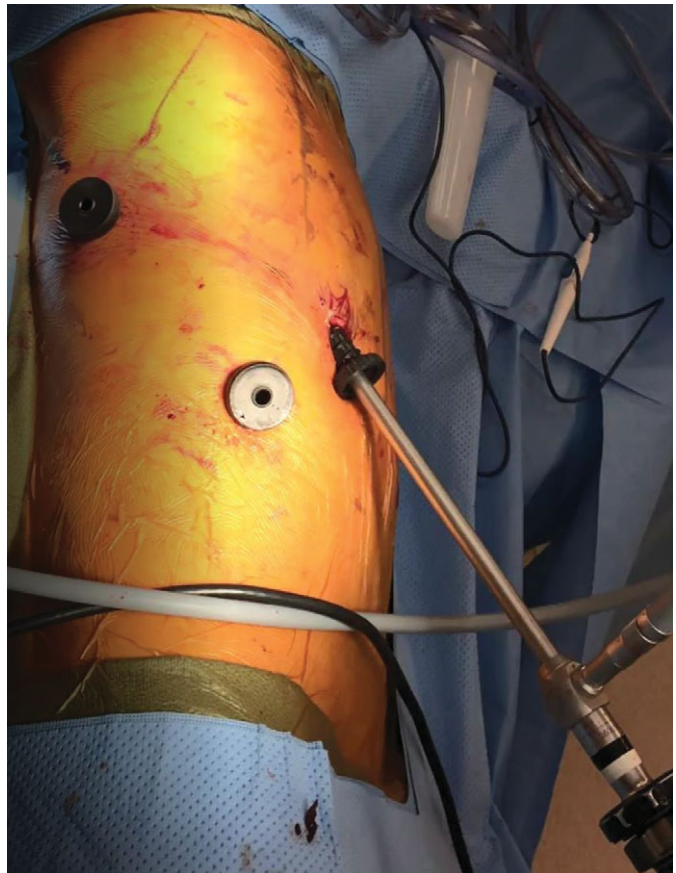


Figure 21.5 Insertion of VATS ports and camera. The number and sites of ports should be determined by the location of the hemothorax.

- Once in the thorax, adhesions are taken down using blunt dissection and power irrigation to help facilitate complete lung isolation.
- The retained hemothorax is evacuated via intermittent suction irrigation with copious warm saline or sterile water irrigation. If thick and organized, the working port can be removed and a hand-held Yankaur suction instrument may be inserted. A power irrigator with suction may be used to break up clots and peel off pseudomembranes from around the lung and the parietal pleura.
- Significant clot burden can be removed with a ring forceps, carefully peeling the rind off the pleura.

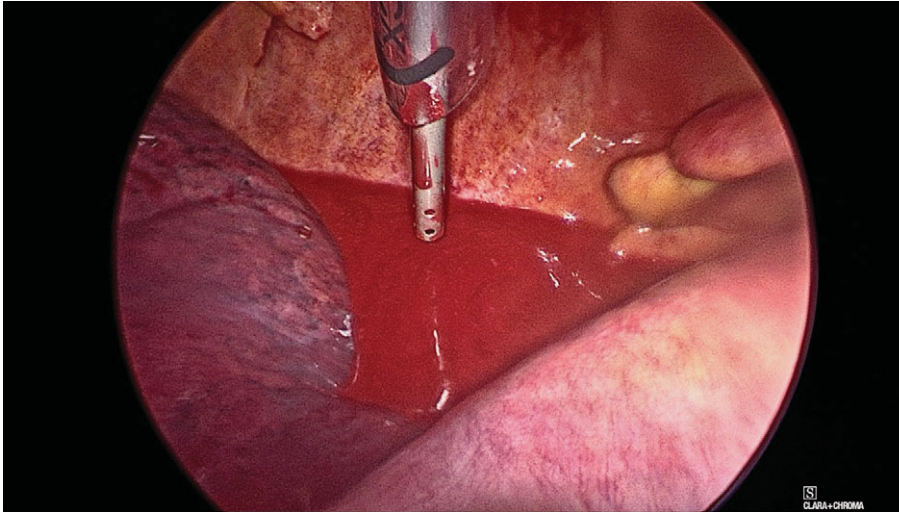


Figure 21.6 Insertion of a suction tip catheter to assist with evacuation of hemothorax.

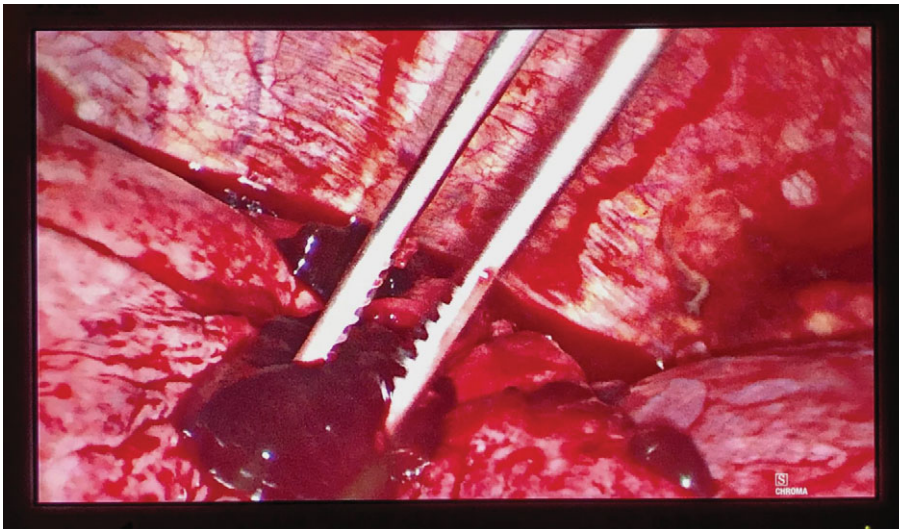


Figure 21.7 Removing of clot with ring forceps.

- If the hemothorax is particularly organized, a decortication procedure may be necessary. Consideration of conversion to open thoracotomy is warranted, given the potential for needing additional exposure and for concerns of bleeding.
- For small tears of the visceral pleura, fibrin sealant may be used. The glue is usually sufficient and suture repair of small leaks is not needed.
- At the conclusion of the case, irrigate the thorax with multiple aliquots of warm saline or sterile water irrigation. Ask the anesthesia provider to reexpand the lung. Look for air bubbles with immersed lung, suggesting tears or leaks.
- Two chest tubes are usually placed through the port sites at completion: one 28-French straight chest tube anterior to the lung and the second basolateral 28-French right angle tube at the costophrenic sulcus.
- Closure of the muscle or fascial layers is sufficient with figure-of-eight absorbable sutures, followed by standard skin closure with subcuticular suture or staples.

Tips and Pitfalls

- The radiological diagnosis of retained hemothorax and planning of VATS should always be made by CT scan. Chest X-ray is not reliable in the accurate diagnosis of retained hemothorax.
- VATS should be performed early, within the first 3–5 days of the injury. Late VATS is more difficult and less successful.
- Patients with bilateral lung injuries may not tolerate collapse of one of the lungs, usually needed for the VATS.
- Remember to perform intercostal nerve and pleural blocks under direct visualization thoracoscopically to reduce postoperative pain.

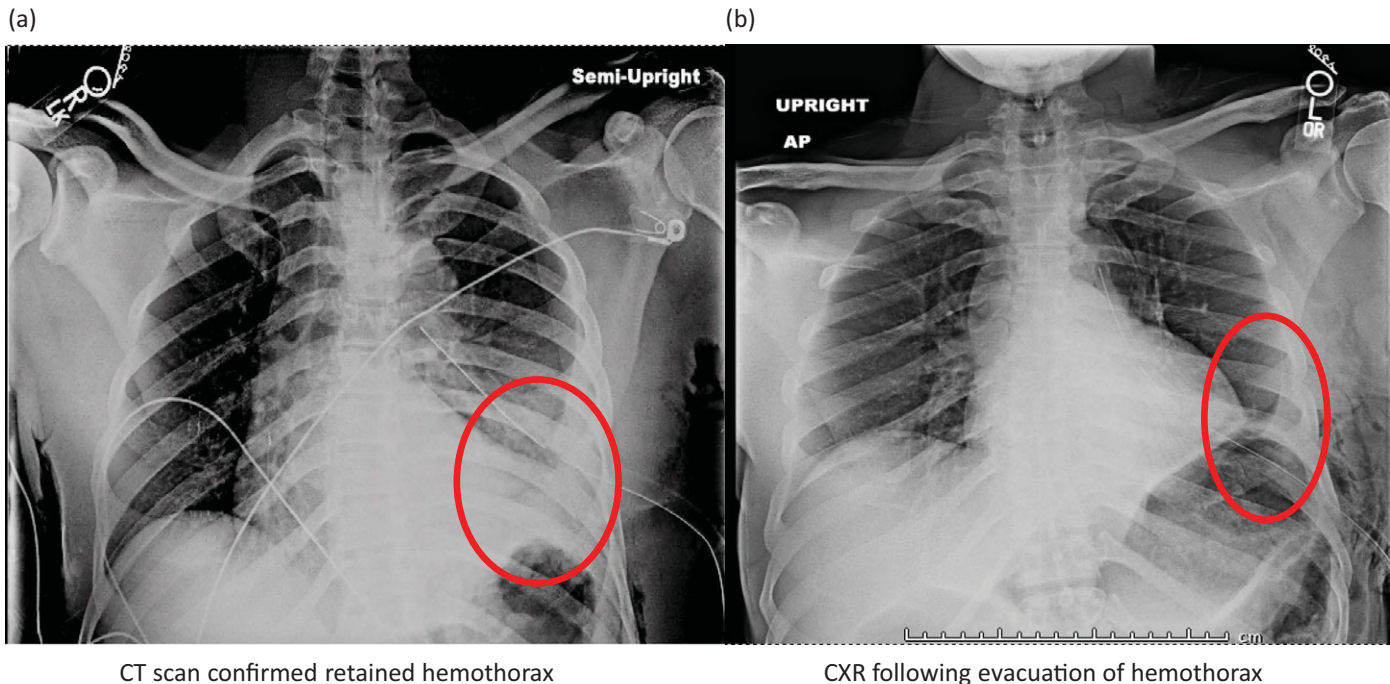


Figure 21.8 (a, b) Chest X-ray pre- and post-VATS evacuation of hemothorax.

General Principles of Abdominal Operations for Trauma

Damon Clark, Zachary D. Warriner, and Lisa L. Schlitzkus

Surgical Anatomy

- The anterior abdominal wall has four muscles: The external oblique, the internal oblique, the transversalis, and the rectus muscles. The aponeuroses of the first three muscles form the rectus sheath, which encloses the rectus abdominis muscle.
- The linea alba is a midline aponeurosis that runs from the xiphoid process to the pubic symphysis and separates the left and right rectus abdominis muscles. It is widest just above the umbilicus, facilitating entry into the peritoneal cavity.
- For vascular trauma purposes, the retroperitoneum is conventionally divided into four anatomic areas:
 - Zone 1: Extends from the aortic hiatus to the sacral promontory. This zone is subdivided into the supramesocolic and inframesocolic areas. The supramesocolic area contains the suprarenal aorta and its major branches (celiac axis, superior mesenteric artery (SMA), and renal arteries), the upper inferior vena cava (IVC) with its major branches, and the superior mesenteric vein (SMV). The inframesocolic area contains the infrarenal aorta and IVC.
 - Zone 2: Includes the kidneys, paracolic gutters, renal vessels, and ureters.
 - Zone 3: Includes the pelvic retroperitoneum, containing the iliac vessels and ureters.
 - Zone 4: Includes the perihepatic area, with the hepatic artery, the portal vein, the retrohepatic IVC, and hepatic veins.

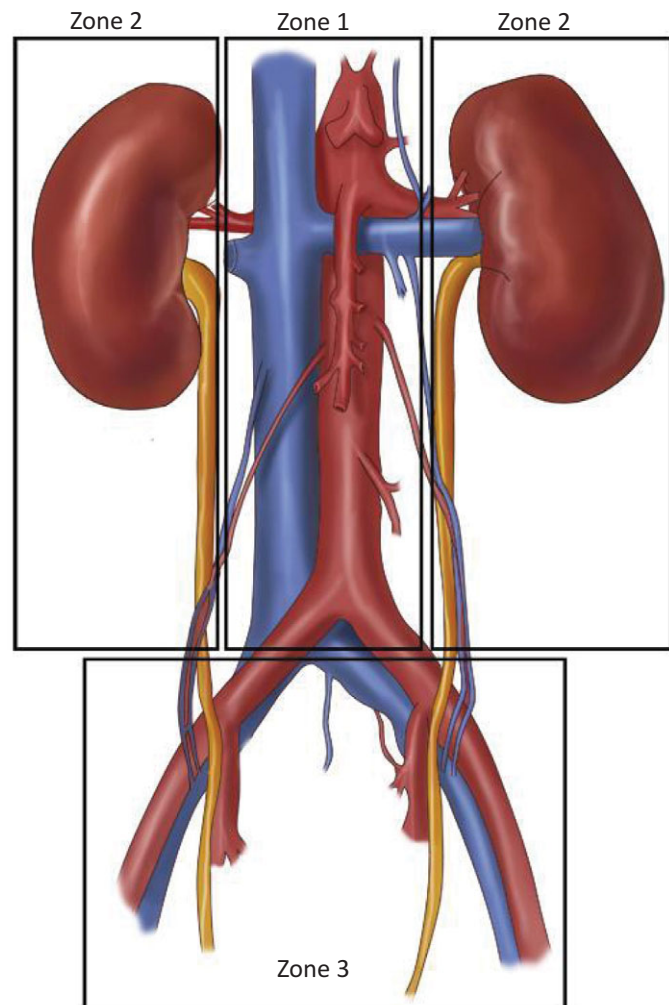


Figure 22.1 Retroperitoneal vascular zones. Zone 1 includes the midline vessels from the aortic hiatus to the sacral promontory. Zone 2 includes the kidneys and renal vessels. Zone 3 includes the pelvic retroperitoneum with contained iliac vessels.

General Technical Principles

- A laparotomy for bleeding is different from a laparotomy for peritonitis.
- The top priority of the surgeon is to stop the bleeding. This should be followed by a methodical exploration of all structures to identify and repair other non-life-threatening injuries.
- In appropriate cases, consider early damage control before major physiological deterioration (coagulopathy, hypothermia, acidosis) occurs. In determining the need for damage control, the surgeon needs to take into account the nature of the injury, associated injuries, the physiological condition of the patient, the hospital capabilities, the skillset of the surgeon, and time required to achieve definitive repair.
- Removal versus repair for organs, such as the spleen and kidney, should be determined by the injury severity and physiologic condition of the patient.
- If damage control packing does not stop the bleeding, do not terminate the operation. Re-explore, identify, and control any surgical bleeding.

- In damage-control procedures, the abdomen should always be left open, using temporary closure techniques. This prevents the development of intra-abdominal hypertension or abdominal compartment syndrome and allows immediate repeat exploration if necessary.

Positioning of Patient and Skin Preparation

- The patient should be placed in the supine position with the arms abducted to 90° to allow anesthesia to obtain access for resuscitation.
- If there is concern for rectal or anal canal injury, the patient may be placed in lithotomy position.
- The bed rails should be free and exposed for fixed surgical retractor placement bilaterally.
- The patient should undergo a standard trauma preparation from chin to knees and laterally to the bed. Inclusion of the groins in the field is important because of the possibility of the need of saphenous vein graft.



Figure 22.2 Position and skin preparation for trauma laparotomy. The patient should be prepped from chin to knees and laterally to the bed (posterior axillary lines).

Incisions

- A full midline laparotomy is the standard incision in trauma. The extent of the incision is determined by the suspected location of injury and the condition of the patient. The incision should be long enough to provide comfortable exposure and allow a complete exploration of the abdomen. A xiphoid to pubic symphysis incision should be considered in hemodynamically unstable patients with blunt trauma, as well as penetrating trauma and unknown missile trajectories. The concept of routine xiphoid to pubic symphysis incision in all trauma laparotomies is not advisable.

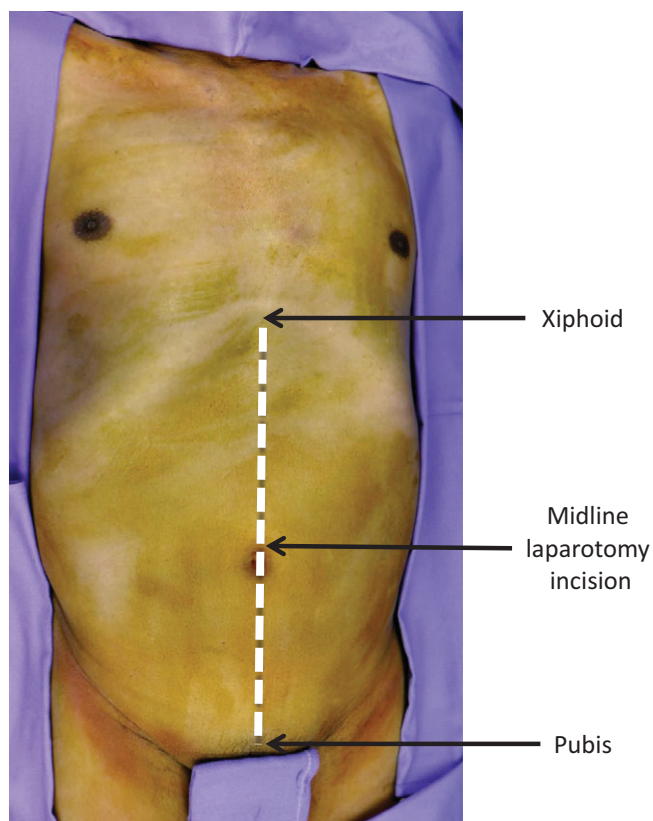


Figure 22.3 Midline laparotomy is performed between the xiphoid and pubis. The extent of incision and location along this is dictated by the suspected injury burden.

- In a hypotensive patient, the abdomen should be entered quickly, without wasting time for local hemostasis. The skin, subcutaneous tissue, and the linea alba are incised sharply. The best place to incise the linea alba is 2–3 cm above the umbilicus, where the aponeurosis is at its widest part and there is a reduced risk of entering the rectus sheath. The preperitoneal fat is then swept away and the peritoneum is identified and entered. A finger can be used to enter the peritoneal cavity just superior to the umbilicus at the thinnest point.

(a)

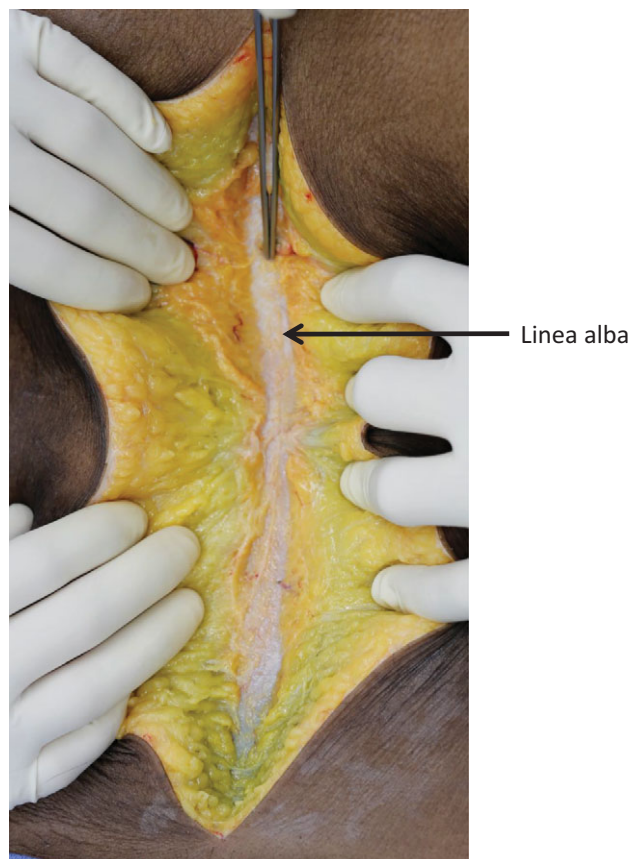
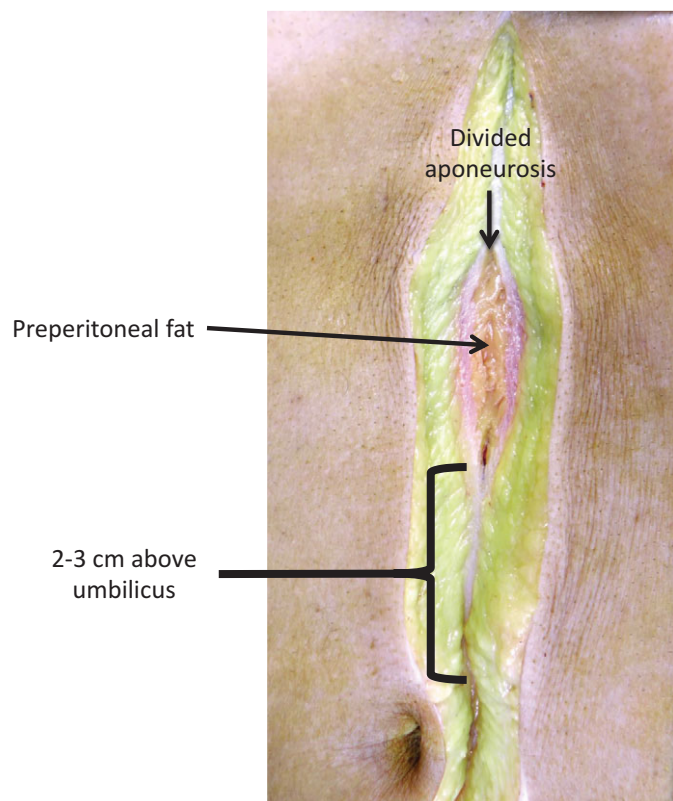
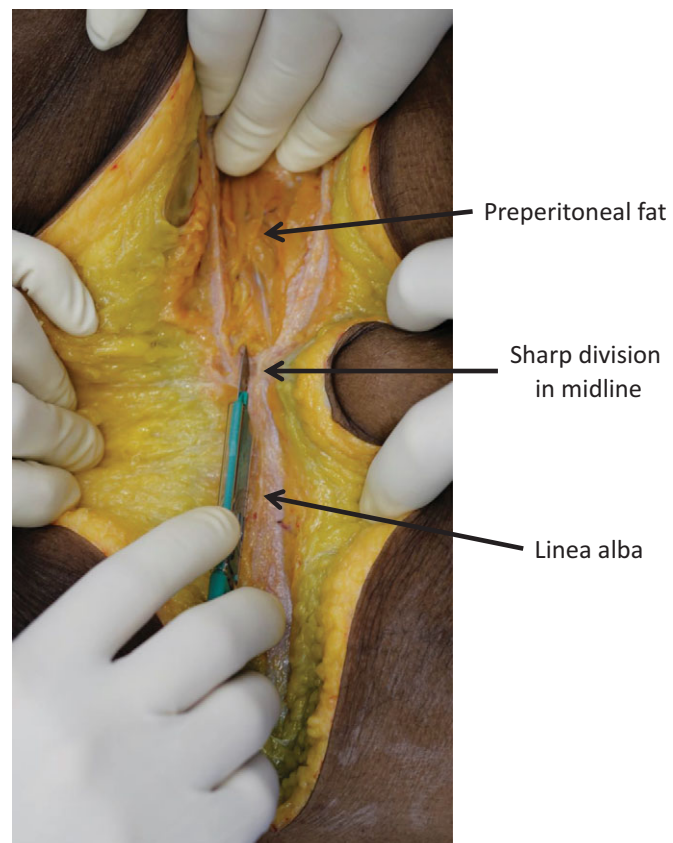


Figure 22.4 (a) Midline laparotomy incision. The skin and subcutaneous tissue are incised, exposing the linea alba. **(b)** The linea alba is incised 2–3 cm above the umbilicus, where the aponeurosis is at its widest. **(c)** Sharp dissection is continued along the aponeurosis in the midline, avoiding entry into the rectus sheath, further exposing the underlying preperitoneal fat. The peritoneum is entered sharply or bluntly **(d)** and extended with sharp dissection **(e)** along the entire length of the incision. **(f)** The divided linea alba and peritoneum with underlying omentum.

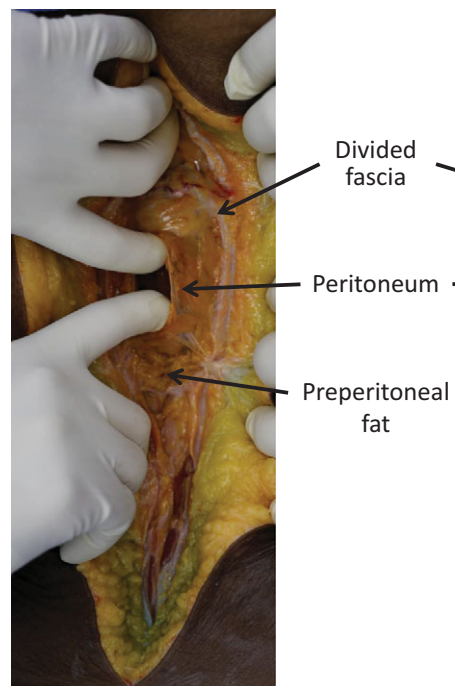
(b)



(c)



(d)



(e)

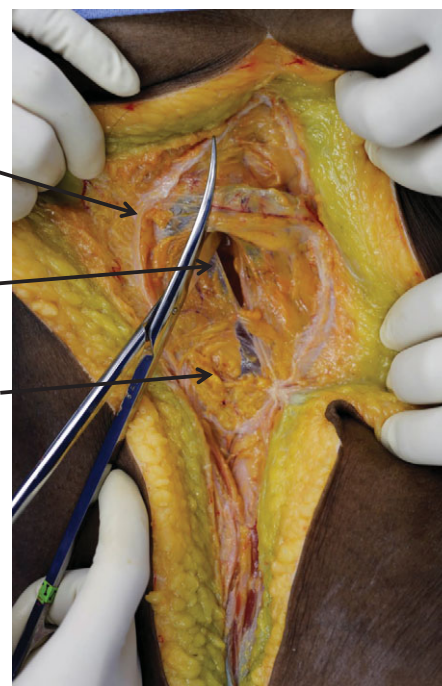


Figure 22.4 (cont.)

(f)

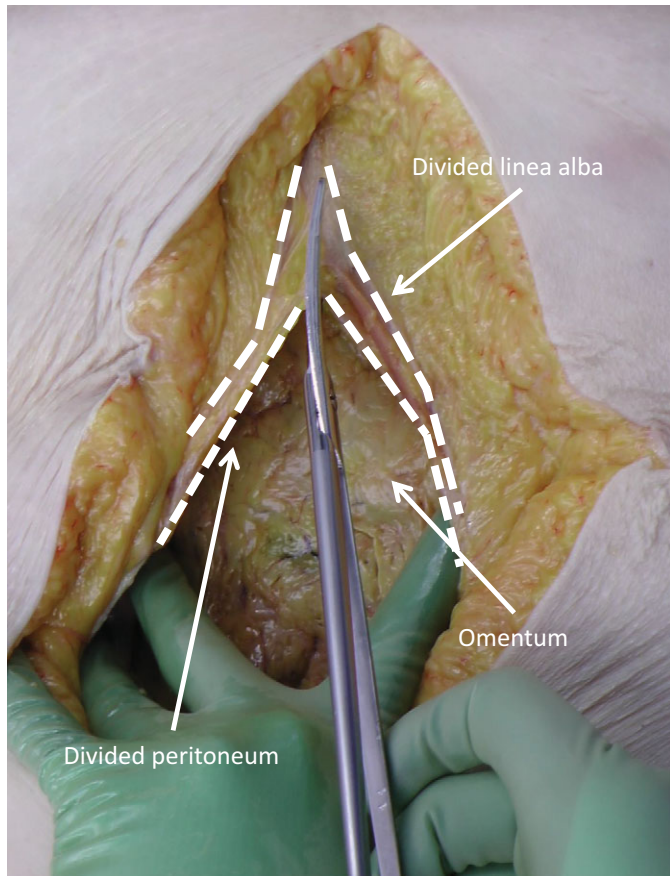


Figure 22.4 (cont.)

- In some cases with complex posterior liver or retrohepatic major venous injuries, the exposure can be improved by adding a right subcostal incision to the standard midline laparotomy. The standard subcostal incision is made 1–2 fingerbreadths below the costal margin. Avoid an acute angle between the two incisions. This helps to prevent ischemic necrosis of the skin. The rectus abdominis, external oblique, internal oblique, and transversalis muscles are each divided. Control of the epigastric artery within the rectus muscle must be assured.

(a)

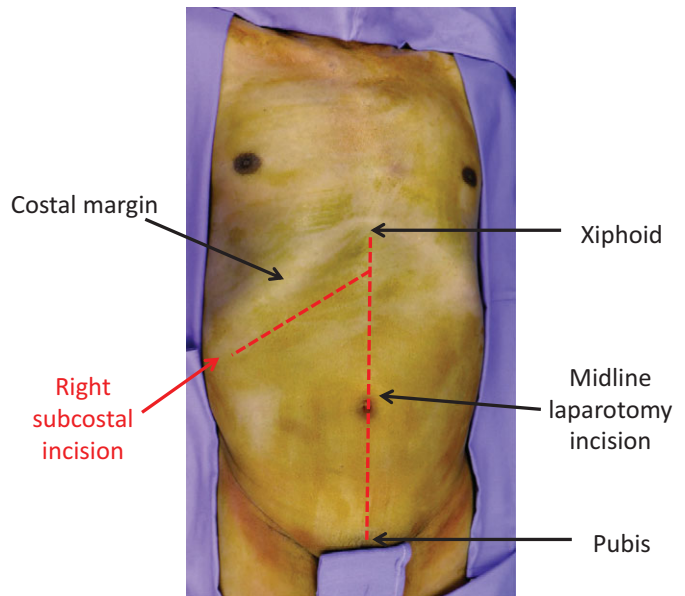


Figure 22.5 (a–c) Addition of a right subcostal incision to the standard midline laparotomy for improved exposure of the liver. The subcostal incision is made 1–2 fingerbreadths below the costal margin. Avoid an acute angle between the two incisions to prevent ischemic necrosis of the skin. **(d)** Poor exposure of the liver through a midline laparotomy. **(e)** Improved exposure of the liver with addition of a right subcostal incision to the midline incision.

(b)



(c)



(d)



(e)

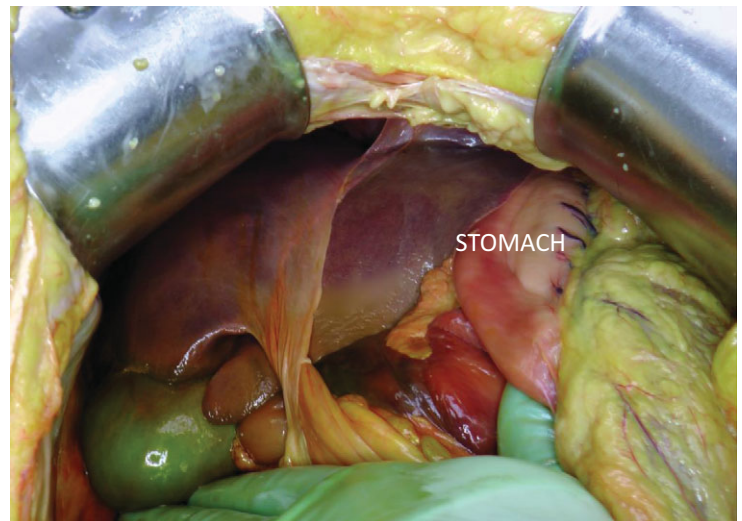


Figure 22.5 (cont.)

- Extension of the midline laparotomy into a median sternotomy can be useful in cases with severe liver injuries requiring atriocaval shunting or total hepatic vascular isolation. The technique of median sternotomy is described in [Chapter 15](#).

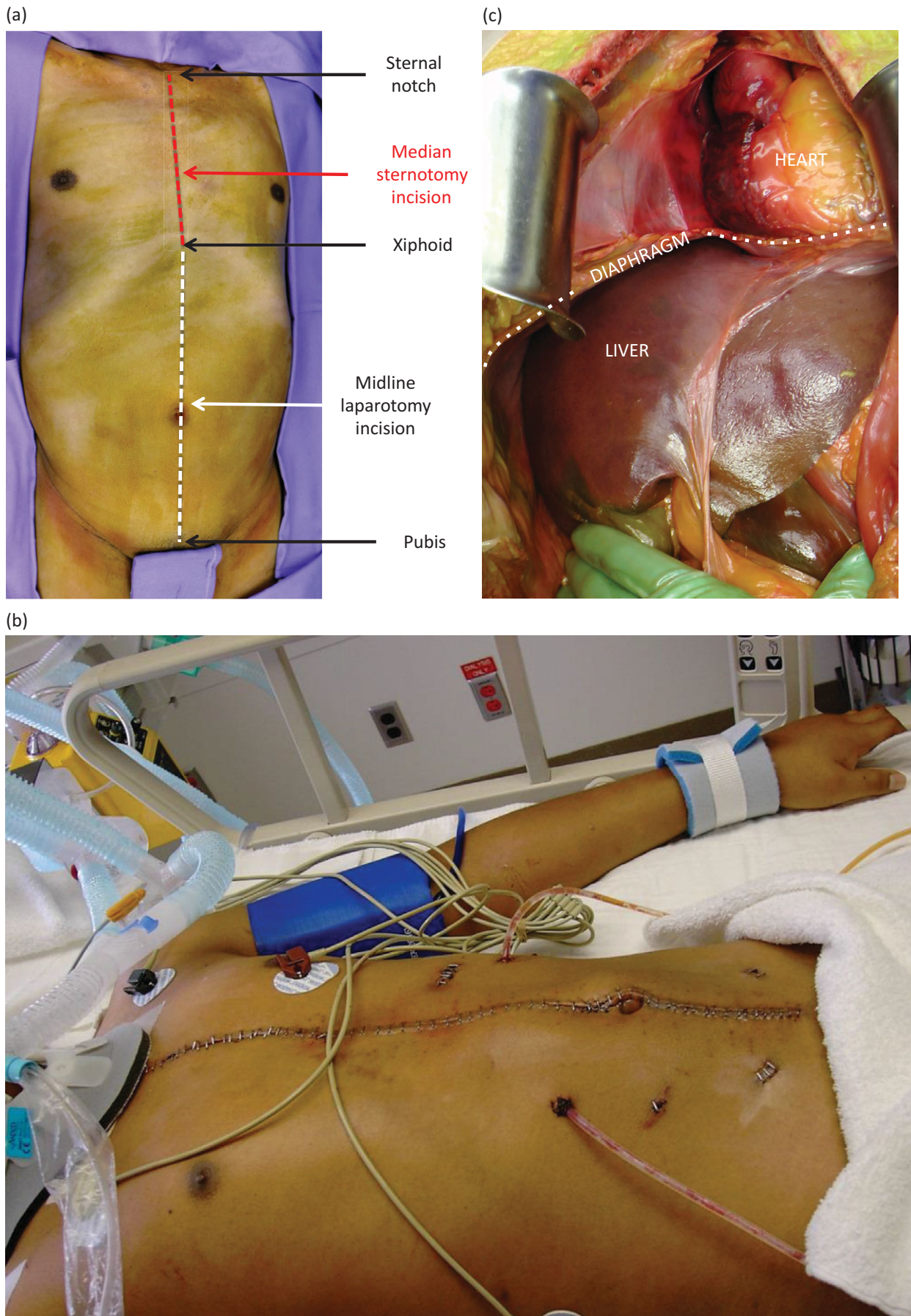


Figure 22.6 (a–c) Extension of the midline laparotomy into a median sternotomy in cases with associated intrathoracic injuries or severe liver injuries requiring atriocaval shunt or total hepatic vascular isolation.

Special Instruments

- A trauma laparotomy set should include basic vascular instruments.
- A Bookwalter retractor or other fixed surgical retractor will facilitate surgical exposure, especially in anatomically difficult areas.
- Headlights are strongly recommended.
- An electrothermal bipolar vessel sealing system device (LigaSure device) may be useful. It expedites division of the mesentery in cases requiring bowel resection. It is also a useful instrument for liver resections and splenectomy.

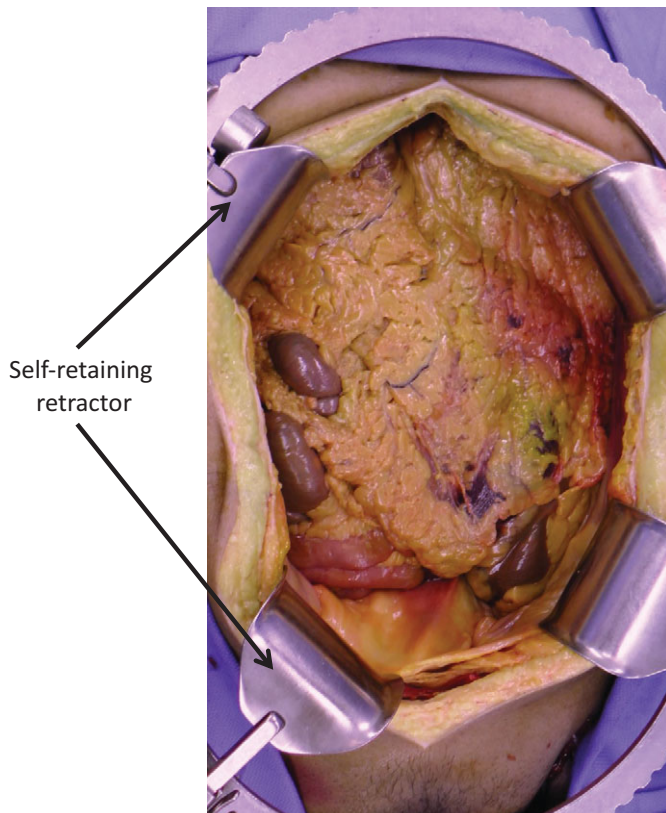


Figure 22.7 Self-retaining Bookwalter retractor in place for improved, hands-free laparotomy exposure.

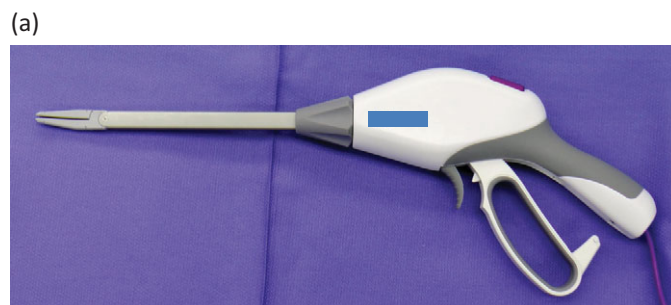


Figure 22.8 Electrothermal bipolar vessel sealing system device (LigaSure device) (a). It is useful in expeditiously dividing the mesentery in cases requiring bowel resection or performing nonanatomic liver resections (b).

(b)



Figure 22.8 (cont.)

Abdominal Exploration

- Upon entering the abdomen, the top priority is the temporary control of all significant bleeding. This can often be achieved by a combination of packing and direct compression.
- Blind four-quadrant packing is not as effective as directed packing. There is no benefit to packing all quadrants in a patient with an isolated stab wound to the left upper quadrant.
- In severe bleeding that is not compressible, consider temporary aortic compression below the diaphragm. Clamping of the infradiaphragmatic aorta can be facilitated by dividing the left crus of the diaphragm at 2 o'clock, where there are no vessels. However, if there is a supramesocolic hematoma or bleeding, infradiaphragmatic aortic clamping may not be possible. In these cases, a left thoracotomy with supradiaphragmatic cross-clamping of the aorta may be needed. Another alternative is placement of an endovascular aortic occlusion balloon, insufflated above the diaphragm. This technique is described in [Chapter 24](#).
- The exposure and exploration are facilitated by complete evisceration of the small bowel. Keep the eviscerated bowel covered with warm and moist towels.
- All hematomas due to penetrating trauma mandate exploration. The only exception is a stable retrohepatic hematoma. Exploring these hematomas is a difficult and potentially dangerous maneuver, and may result in uncontrolled hemorrhage from the retrohepatic IVC or hepatic veins.
- Stable hematomas due to blunt trauma generally should not be explored. However, all paraduodenal hematomas, and large, expanding or leaking hematomas should be explored.

- Should central exposure of the infrarenal aorta or inferior vena cava be required, medial visceral rotation should be performed. This is initiated along the white paracolic line of Toldt, freeing the colon from the peritoneal reflection. Dissection is continued beneath the root of the small bowel

mesentery, allowing complete evisceration of the small bowel, right and transverse colon, with full exposure of the retroperitoneum. Mobilization of the duodenum (Kocher maneuver) may then be performed for complete exposure of the infrahepatic vena cava, renal vessels, and pancreatic head.

(a)

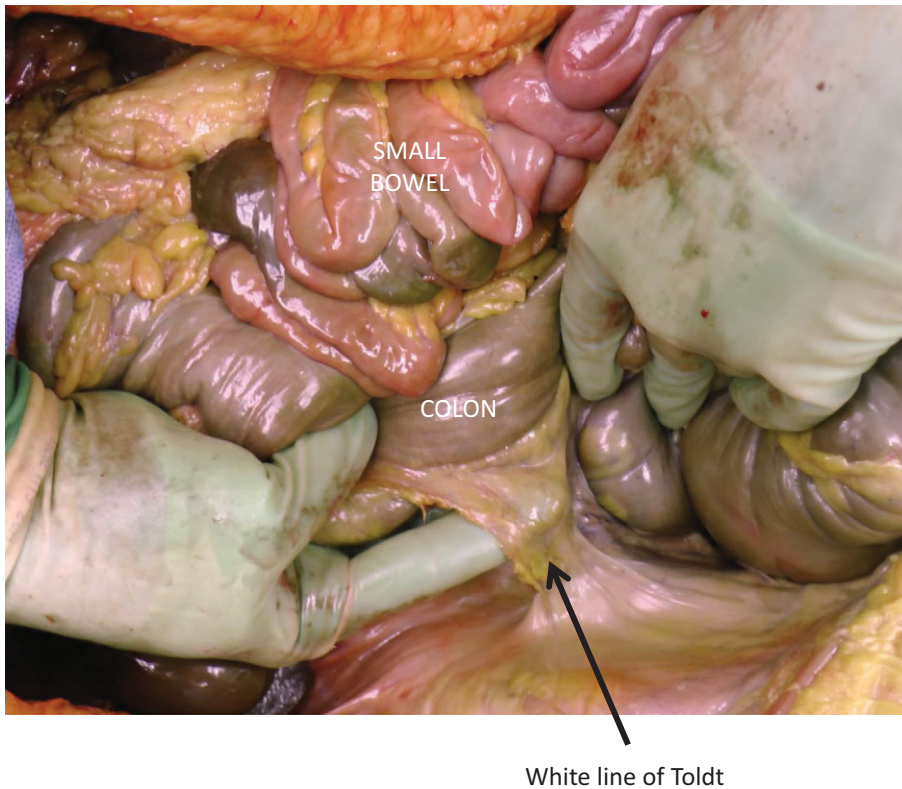
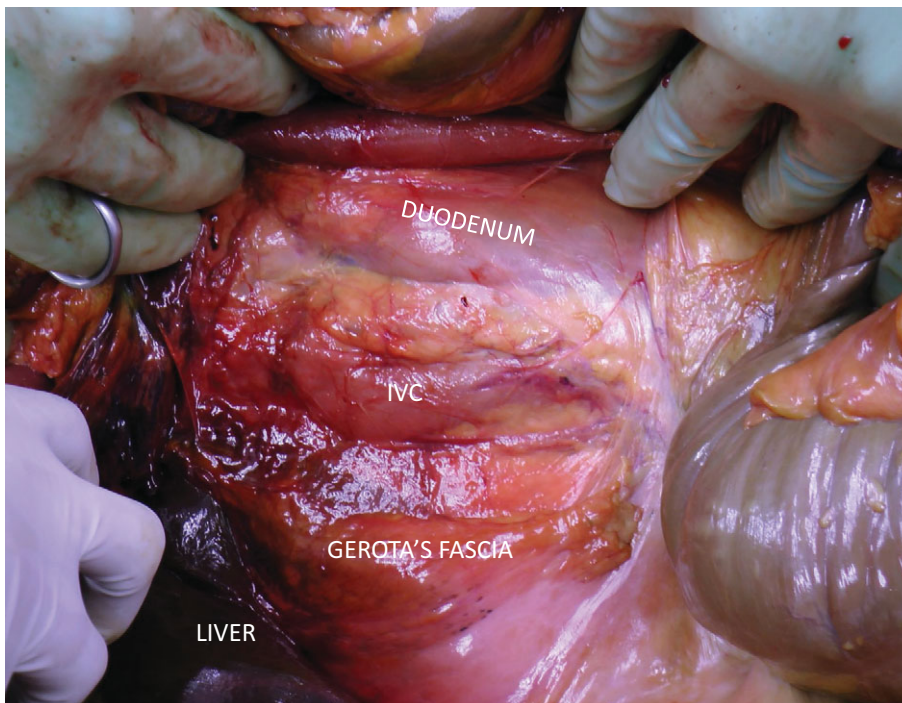
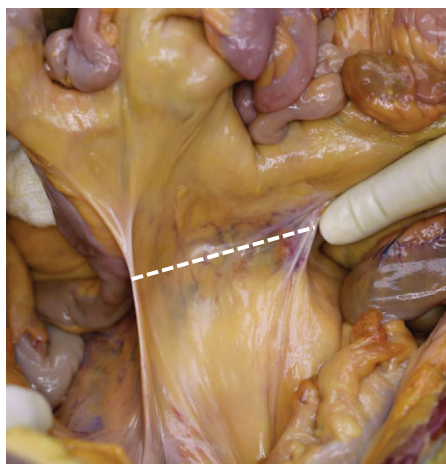


Figure 22.9 (a) Right medial visceral rotation is initiated by dividing the peritoneal reflection of the colon at the white line of Toldt, rotating the colon up and away from the retroperitoneum. (b) Mobilization of the duodenum (Kocher maneuver) exposes the second and third portions of the duodenum, inferior vena cava (IVC), and Gerota's fascia surrounding the right kidney. (c and d) Right medial visceral rotation is continued along the root of the small bowel mesentery beneath the ileocolic vessels by incising the retroperitoneum from the ileocecal junction to the Treitz ligament. This allows evisceration of the small bowel superiorly toward the patient's left chest, exposing the third and fourth portions of the duodenum. (e) Right medial visceral rotation is completed via mobilization of the duodenum (Kocher maneuver), further exposing the underlying inferior vena cava, renal vessels, and posterior portion of the head of the pancreas. (f) Completed right medial visceral rotation with evisceration of the small bowel and right colon towards the patient's head and left chest. This exposes the underlying infrarenal aorta and inferior vena cava.

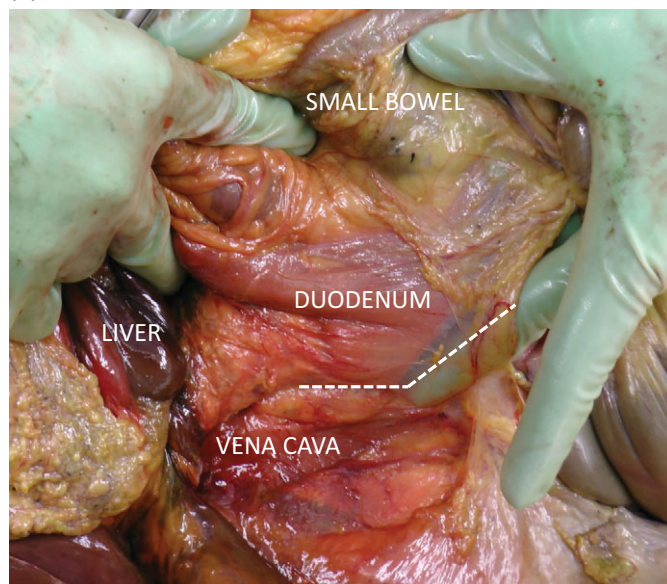
(b)



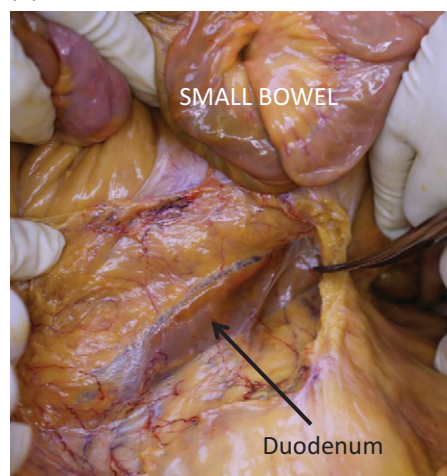
(c)



(e)



(d)



(f)

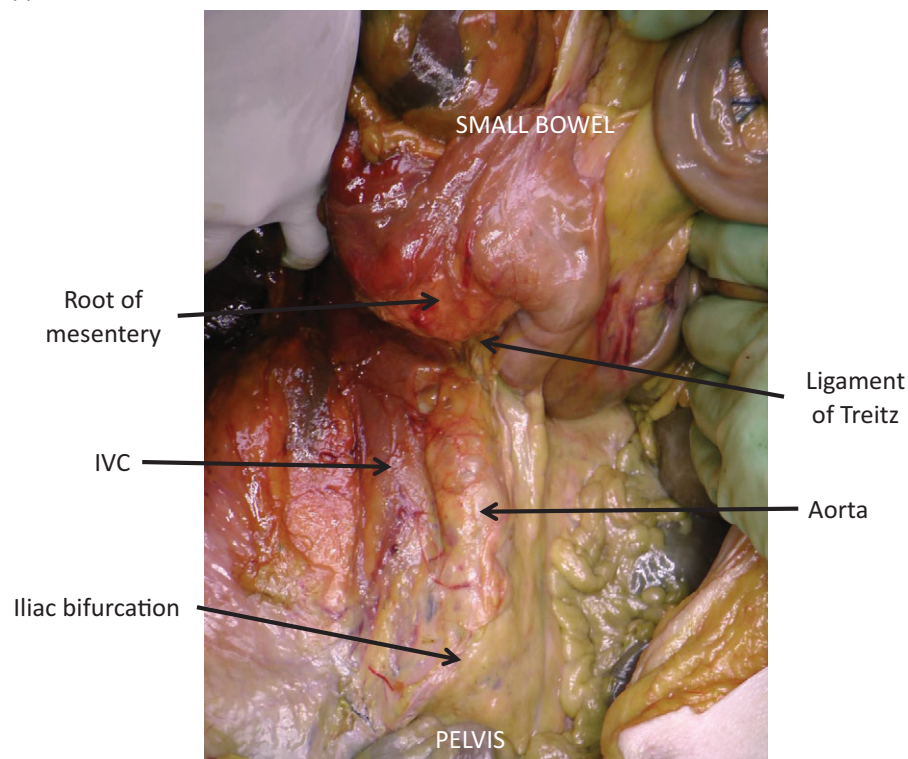
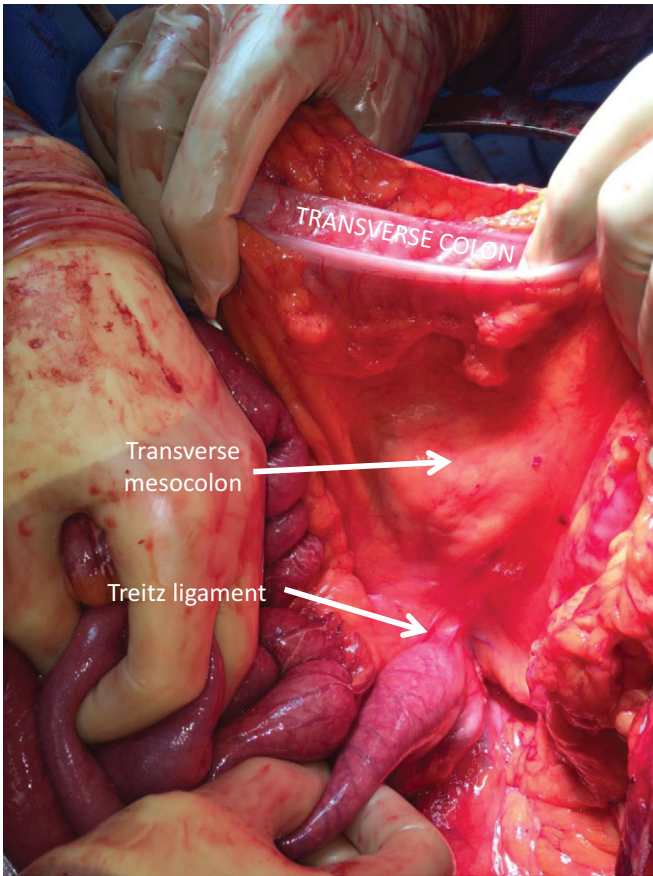


Figure 22.9 (cont.)

- After bleeding control, the abdominal cavity should be explored systematically to identify and treat other injuries.
 - The intestine should be examined from the ligament of Treitz to the rectum. Grasp the transverse colon with two hands and retract towards the patient's chest. The

ligament of Treitz is at the center and base of the transverse mesocolon. Ensure that both sides of the small bowel and mesenteric border are carefully examined so as to not miss an injury. This is especially important in penetrating injuries, particularly shotgun or multiple stab wounds.

(a)



(b)

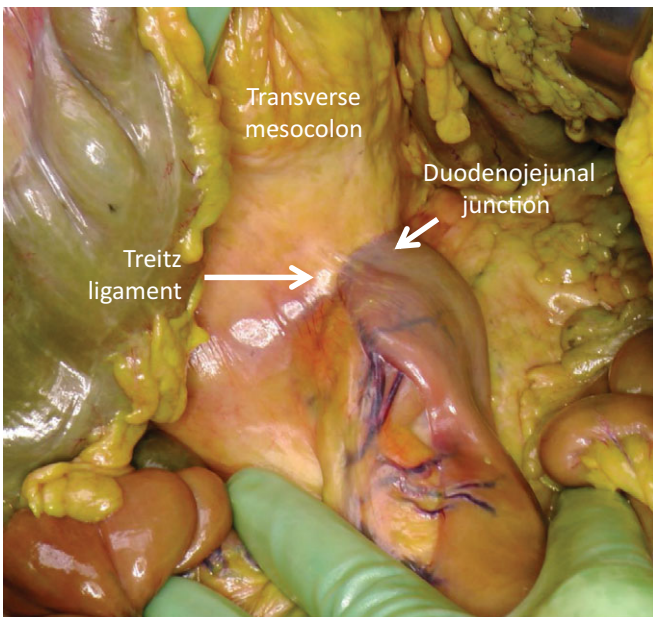


Figure 22.10 (a, b) Identification of the beginning of the small bowel at the Treitz ligament. Grasp the transverse colon with two hands and retract towards the patient's chest. The Treitz ligament is at the middle and base of the transverse mesocolon.

- Evisceration of the small bowel to the left or right allows careful evaluation of the right and left colon. Hematomas in the fat surrounding the colon wall should be explored to exclude an underlying injury.
- The anterior wall of the stomach and the proximal duodenum can be exposed and inspected by retracting the transverse colon towards the patient's pelvis.
- The pancreas and posterior wall of the stomach can be inspected by dividing the gastrocolic ligament between the greater curve of the stomach and the transverse colon. This allows entry into the lesser sac.

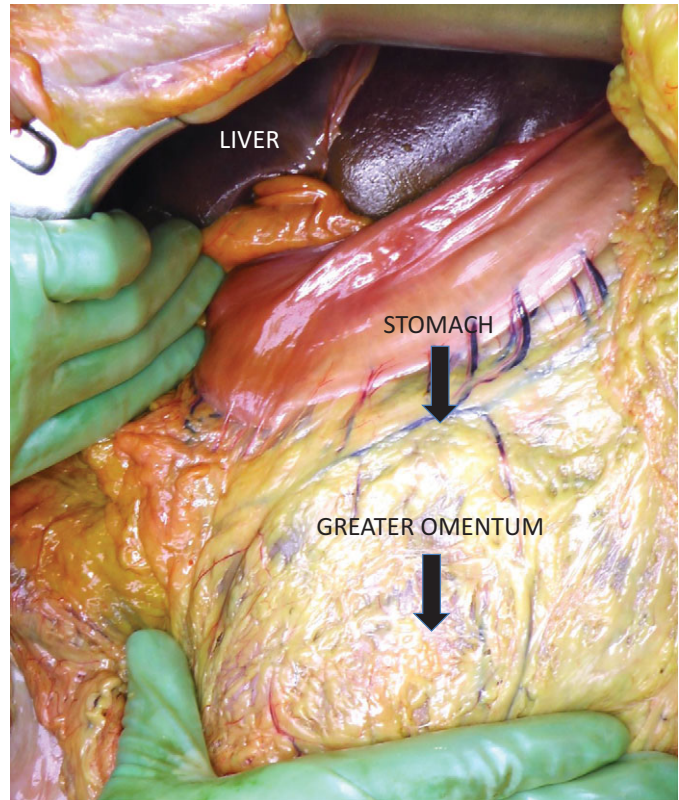


Figure 22.11 Inspection of the anterior wall of the stomach is performed by downward retraction (arrows) on the greater curvature of the stomach and the omentum.

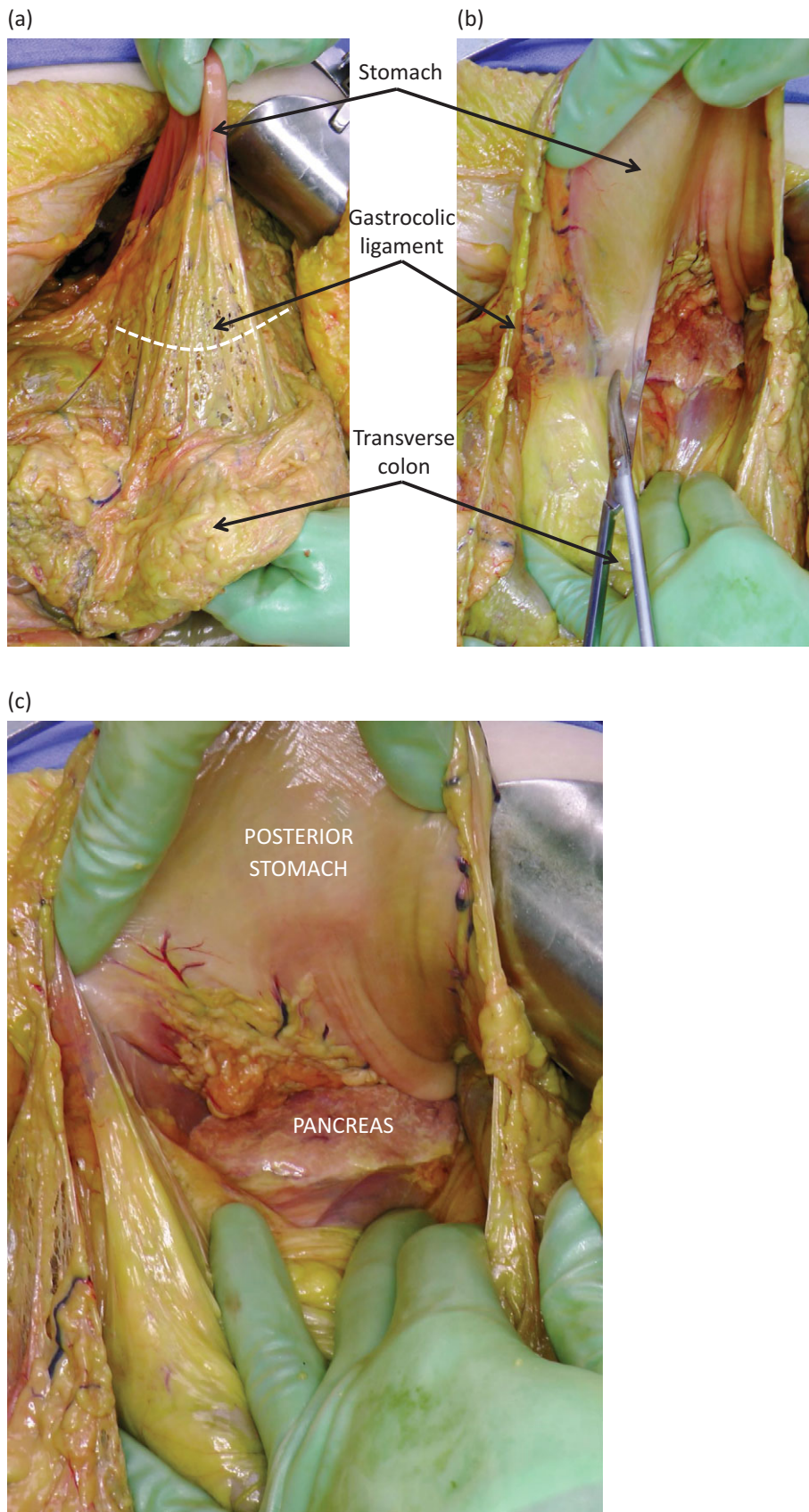


Figure 22.12 (a, b) Division of the gastrocolic ligament for entry into the lesser sac. The stomach is retracted anteriorly and toward the head while the transverse colon is protected and retracted toward the pelvis. The now tense gastrocolic ligament is divided at its thinnest part (dotted white line) and the lesser sac is entered. Avascular attachments posterior to the stomach may be sharply divided to improve this exposure (c) Inspection of the lesser sac. This allows evaluation of the posterior stomach and pancreas for injury.

- The liver and spleen should be palpated and visually inspected for injuries. The inspection may be improved by placing laparotomy pads behind the liver or spleen, elevating them within the wound.
- All hollow viscus subserosal hematomas should be explored and examined for underlying perforation.
- The diaphragm should always be palpated and inspected for injury.
- Both kidneys should be palpated for their presence and normal size. This step is important if a nephrectomy is considered. If the patient can tolerate it, preserve kidney mass whenever possible.

Intestinal Anastomosis

- In trauma, the outcomes are equivalent for hand-sewn versus stapled anastomoses. Data is also similar regarding one-layer versus two-layer anastomoses, as well as continuous versus interrupted sutures. In pediatric cases, a one-layer anastomosis is recommended to avoid anastomotic stenosis.

Abdominal Closure

- Closed drains are recommended in selected cases, such as complex liver or pancreatic injuries. There is no role, however, for routine drainage.
- Fascial closure should be attempted whenever possible. However, for patients at risk of abdominal compartment syndrome or intra-abdominal hypertension, temporary closure is acceptable. In all patients, close postoperative monitoring of intra-abdominal pressures is warranted (see [Chapter 23](#) Damage Control Surgery).

- The skin should be left open in cases where there was intraoperative contamination to prevent incisional wound infection, which may result in postoperative dehiscence or evisceration.

Tips and Pitfalls

- Ongoing communication with the anesthesia team is critical during the operation to determine the potential need for damage control.
- In penetrating abdominal injuries with hemodynamic instability, avoid venous access in the lower extremities, because of the possibility of a proximal injury of the iliac vein or inferior vena cava injuries.
- The surgeon should consider using a headlamp routinely, especially for unknown injuries or those located in difficult anatomical areas.
- Open the linea alba 2–3 cm above the umbilicus, where the aponeurosis is widest to reduce the risk of entering the rectus sheath.
- All hematomas due to penetrating trauma, irrespective of size, should be explored. The only exception is a stable retrohepatic hematoma.
- In multiple small bowel perforations, identify all perforations before starting repairs or resections. Resecting one segment with a single anastomosis may be safer than multiple intestinal repairs or resections in close proximity, increasing the potential for anastomotic leak.
- In complex abdominal trauma where the abdominal wall is closed at the index operation, it is important to monitor bladder pressures, peak airway pressures, and other physiologic parameters postoperatively for the potential development of intra-abdominal hypertension or compartment syndrome.

Damage Control Surgery

Mark J. Kaplan and Demetrios Demetriades

General Principles

- Damage Control (DC) initially referred to surgical techniques used in the operating room. This concept has now been expanded to include damage control resuscitation, which includes permissive hypotension, early empiric blood component therapy, and the prevention and treatment of hypothermia and acidosis.
- DC techniques can be applied to most anatomical areas and structures, including the neck, chest, abdomen, vessels, and fractures.
- DC surgery is an abbreviated procedure with the goal of rapidly controlling bleeding and contamination so that the initial procedure can be terminated, decreasing surgical stress and allowing a focus on resuscitation. This should be considered in patients with progressive physiologic exhaustion, who are at risk of irreversible shock and death. After physiologic resuscitation, the patient is returned to the operating room for definitive reconstruction and eventual definitive closure of the involved cavity.
- The standard indications for DC include:
 - Patients in “extremis,” with coagulopathy, hypothermia $<35^{\circ}\text{C}$, acidosis (base deficit >15 mmol/L), elevated lactate, prolonged hypotension on pressors.
 - Bleeding from difficult to control injuries (complex liver injuries, retroperitoneum, mediastinum, neck, and complex vascular).
 - In suboptimal environments, such as the rural or battlefield setting or with inexperienced surgeons without the adequate skillset to definitively manage the injury.
- For maximum benefit, damage control should be considered early, before the patient reaches the “in extremis” condition! Consider the nature of the injury, the

physiologic condition of the patient, comorbid conditions, the available resources, and the experience of the surgeon. The timing of DC surgery is critical in determining the outcome.

Damage Control in the Abdomen

- In abdominal DC surgery, the goal of the initial exploration is temporary control of bleeding and spillage from a hollow viscus injury. The definitive reconstruction is performed semi-electively, at a later stage, ideally within 24–48 hours, after physiological stabilization.
- Temporary closure can be obtained by use of a vacuum-assisted closure system.

Temporary Control of Abdominal Bleeding

- Temporary bleeding control can be achieved by tight gauze packing of the source of the bleeding (liver, retroperitoneum, or pelvis), application of local hemostatic agents, balloon tamponade in some cases (i.e. bleeding from a deep penetrating tract in the liver or the retroperitoneum), ligation instead of repair of major venous injuries, temporary shunting of injured arteries, or any combination of the above (see appropriate chapters for specific DC techniques for the liver or vessels).
- Technique of liver gauze packing (see [Chapter 27](#)) following ligation of major sites of bleeding and nonanatomical resection of nonviable liver, DC with tight packing tamponade should be considered if there is persistent bleeding. The liver is wrapped with absorbable mesh and gauze packing is applied around it. The mesh may stay permanently in the abdomen and can facilitate the removal of the gauze at the second-look laparotomy, without causing bleeding.

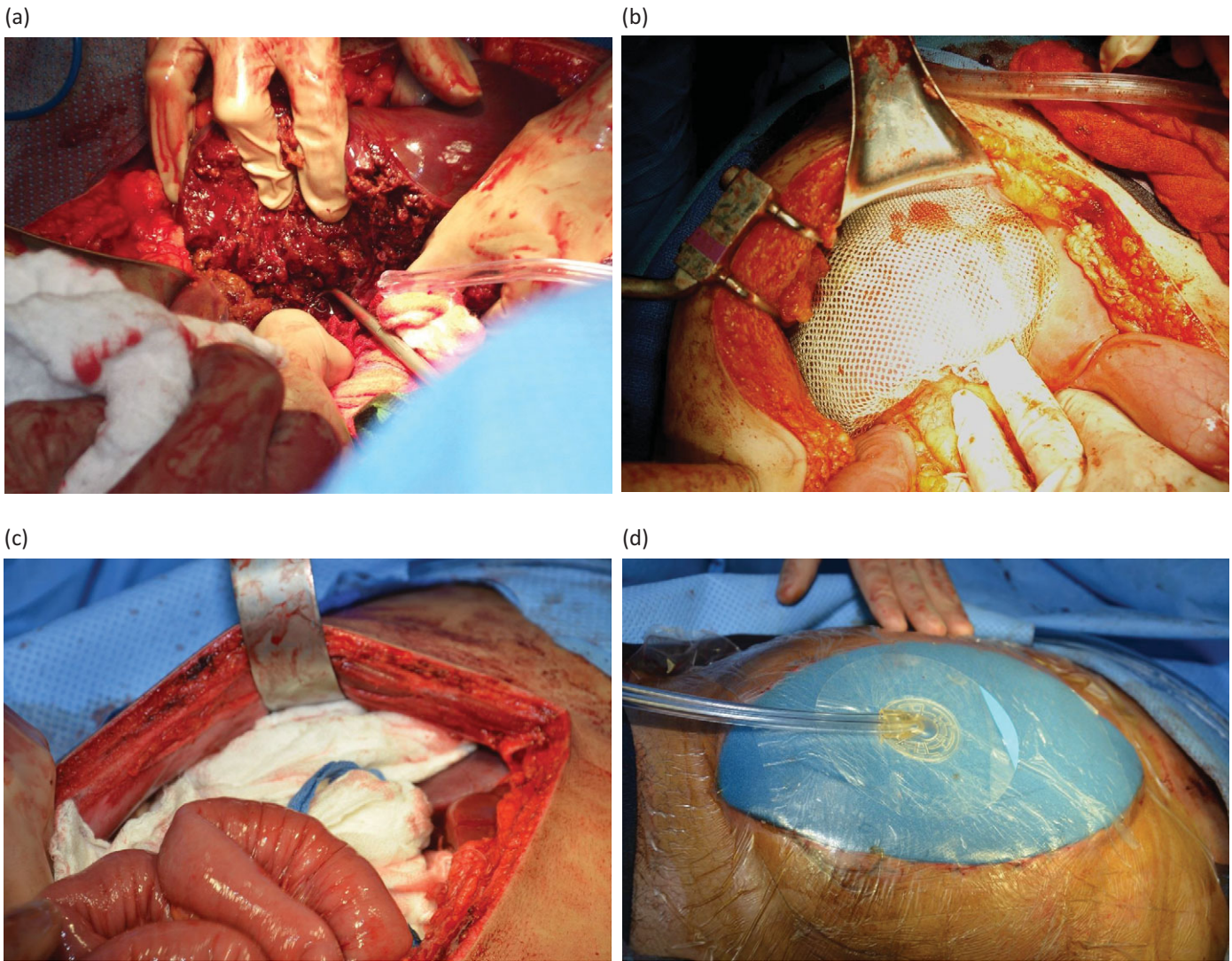


Figure 23.1 Severe liver injury requiring damage control (DC) with packing. After ligation of major bleeders and nonanatomical debridement (a), the liver is tightly wrapped with absorbable mesh (b). DC for severe liver injury. The liver injury is tightly packed with gauze (c) and temporary abdominal wall closure achieved with ABThera negative pressure system (d).

- Local hemostatic agents are usually effective in controlling minor bleeding, but they rarely work in major hemorrhage.

Control of Intestinal Spillage

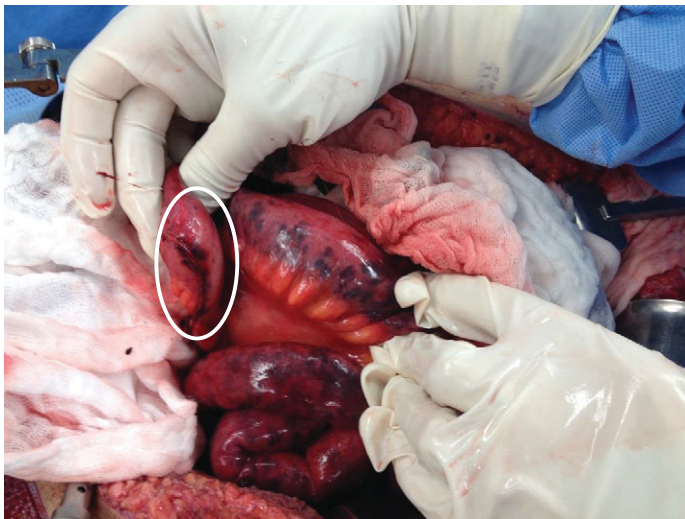
- Ligation or stapling of the injured bowel, without reanastomosis, has been recommended for temporary control of intestinal content spillage (Figure 23.2). Definitive reconstruction is performed at a later stage, usually about 24–36 hours after the initial operation. Some surgeons do not support this approach because of the

concern for creating a closed-loop intestinal obstruction, which may promote bacterial and toxin translocation and aggravate bowel ischemia, especially in patients requiring vasopressors (Figure 23.3a, b). Therefore, bowel left in discontinuity should be reanastomosis within 24 hours to minimize complications. With anticipation of the discontinuity lasting longer than 24 hours, primary anastomosis or ostomy should be considered. We support reconstruction of the bowel or ostomy diversion during the DC operation whenever possible.



Figure 23.2 Damage control to stop intestinal spillage can be achieved by stapling of the injured bowel (black circles), without reanastomosis.

(a)



(b)



Figure 23.3 (a) Bowel ischemia proximal to the staple line (white circle), 48 hours after damage control and bowel discontinuity. (b) This shows the necrotic mucosa.

Temporary Abdominal Wall Closure

- Following DC procedures, the abdominal fascia or skin should never be closed because of the high risk of IAH or ACS. Temporary abdominal closure (TAC) should always be performed.
- The technique used for temporary abdominal wall closure can influence outcomes, including survival, complications, and success rates, as well as time to definitive fascia closure.
- The ideal method of TAC should prevent evisceration, actively remove any infected or toxin-loaded fluid from the peritoneal cavity, minimize the risk of formation of enteroatmospheric fistulas, preserve the fascia and the abdominal wall domain, facilitate reoperation, and help achieve early definitive closure.
- Numerous materials and techniques have been used for temporary closure over the last decade. They include the

“Bogota bag,” the Wittmann patch, absorbable synthetic meshes, and various negative pressure therapy (NPT) techniques. The NPT techniques have the advantage of active removal of contaminated or toxin-rich peritoneal fluid, fluid while minimizing abdominal wall retraction.

1. The “Bogota bag” can easily be constructed with a 3 L sterile irrigation bag or a sterile X-ray cassette cover stapled or sutured to the fascia or the skin. It prevents evisceration of the abdominal contents, while minimizing the risk of IAH or ACS. Bogota bag has limited use in cases with DC for intra-abdominal bleeding, where definitive abdominal closure is anticipated within the next 24–48 hours. Its major disadvantage is that it does not allow the effective removal of any contaminated or toxin and cytokine-rich intraperitoneal fluid, and it does not prevent the loss of abdominal wall domain.

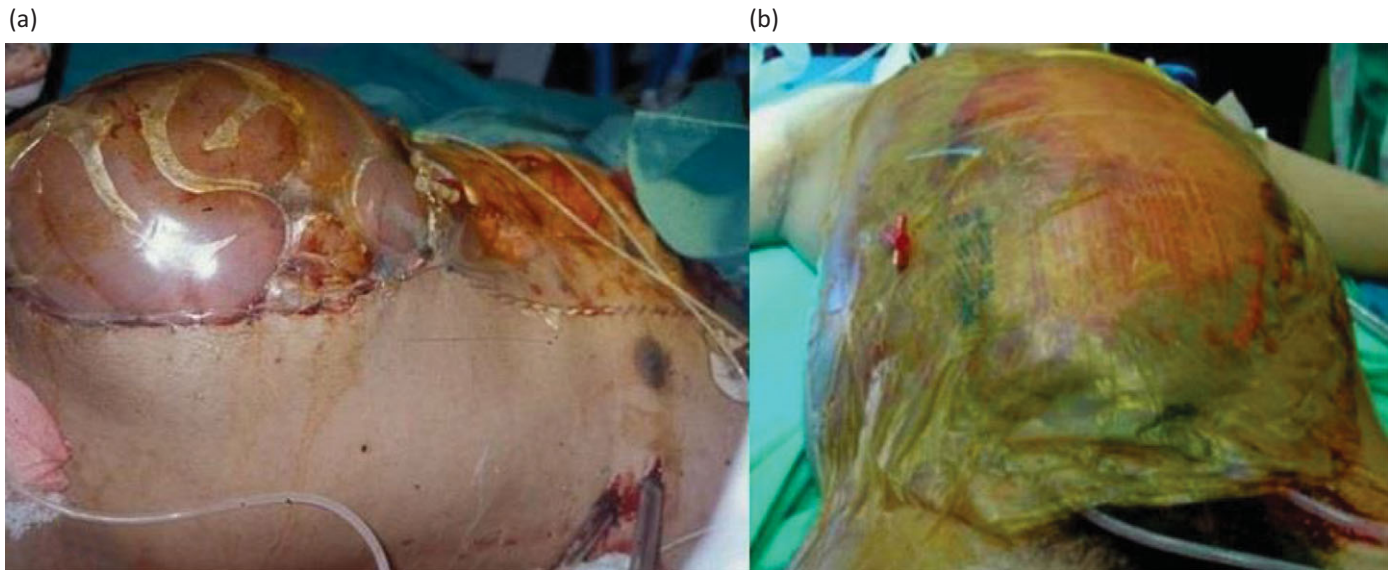


Figure 23.4 Temporary abdominal and sternotomy closure (a), and abdomen (b), with plastic sheet (Bogota bag). This approach does not allow the effective removal of peritoneal fluid and does not preserve the abdominal domain.

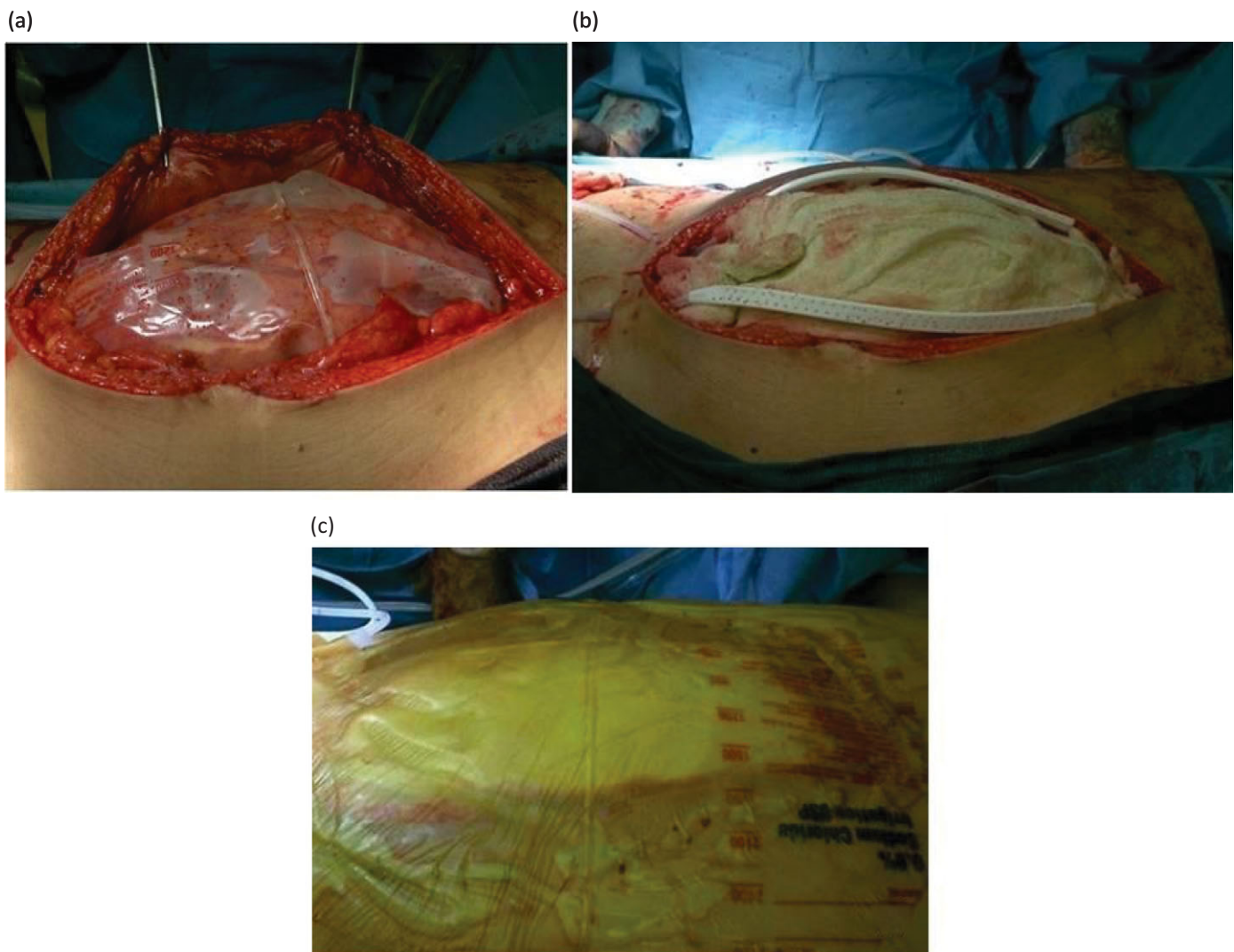


Figure 23.5 Barker's vacuum pack technique. Fenestrated, nonadherent polyethylene sheet is placed over the bowel and under the peritoneum (a), and covered by moist surgical towels or gauze. Two silicone drains are placed over the gauze (b), and a transparent adhesive drape is placed over the wound to maintain a closed seal. The drains are connected to continuous wall suction (c).



Figure 23.6 ABThera negative pressure system for temporary abdominal closure: A: visceral protective layer, B: fenestrated foam, C: semi-occlusive adhesive drape, D: tubing with interface pad, E: pump.

2. NPT techniques have revolutionized the management of the open abdomen and improved survival, morbidity, and success rates of primary fascia closure. The most commonly used NPT techniques are the Barker's vacuum pack technique and the ABThera system (KCI, San Antonio, Texas).

- (a) Barker's vacuum pack technique consists of a fenestrated, nonadherent polyethylene sheet, which is placed over the bowel and under the peritoneum, covered by moist surgical towels or gauze, two large silicone drains placed over the towels, and a transparent adhesive drape over the wound to maintain a closed seal. The drains are connected to continuous wall suction at 100–150 mmHg. The dressing system is changed every 24–48 hours and every time the fascia at the top and bottom of the wound is approximated, if it can be done without tension. Some surgeons use this technique for the

first 24–48 hours postoperatively, switching to the VAC therapy afterwards.

- (b) The ABThera (KCI) is a commonly used NPT system. It consists of four component layers:

- The first layer is the visceral protective layer (VPL), made of a polyurethane foam with six radiating foam extensions enveloped in a polyethylene sheet with small fenestrations. This layer is placed directly over the bowel and tucked under the peritoneum, into the paracolic gutters and pelvis. The VPL does not need to be cut; however, if it is, the foam squares should be divided in the middle with the residual foam pulled out and discarded. Lateral slits should be made at the level of any ostomies or feeding tubes to allow the VPL to fully extend around them.
- The second layer consists of fenestrated ovoid-shape foam cut into the correct size and placed over the protective foam, under the fascia, over the VPL.

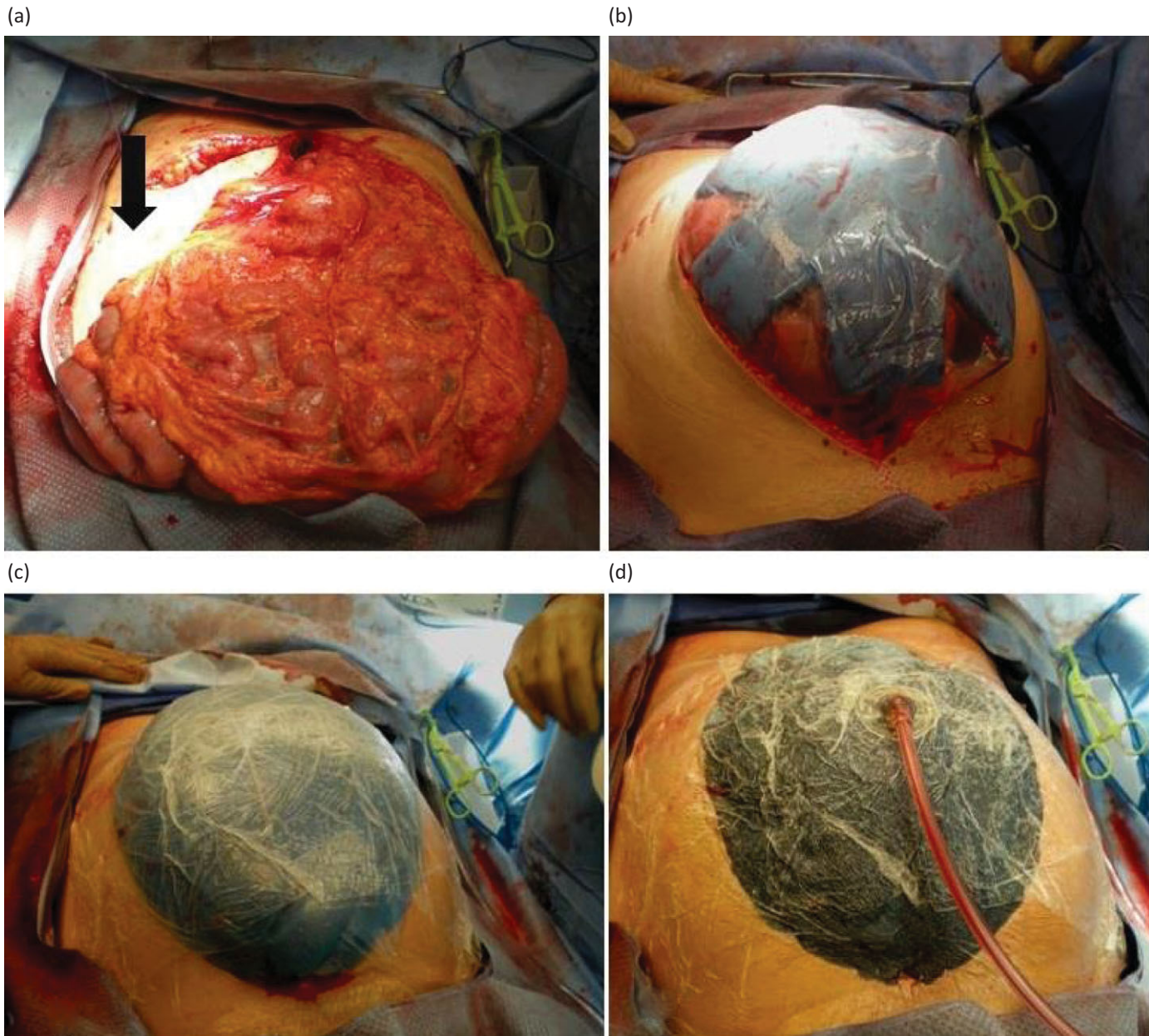


Figure 23.7 Application of ABThera for temporary abdominal closure. **(a)** Severe liver injury with perihepatic packing (arrow). **(b)** Application of the visceral protective layer over the intestine and under the peritoneum. **(c)** Application of two layers of fenestrated foam (one under the peritoneum and one between the edges of the abdominal wound), covered with transparent occlusive adhesive drape. **(d)** Interface pad and suction tubing.

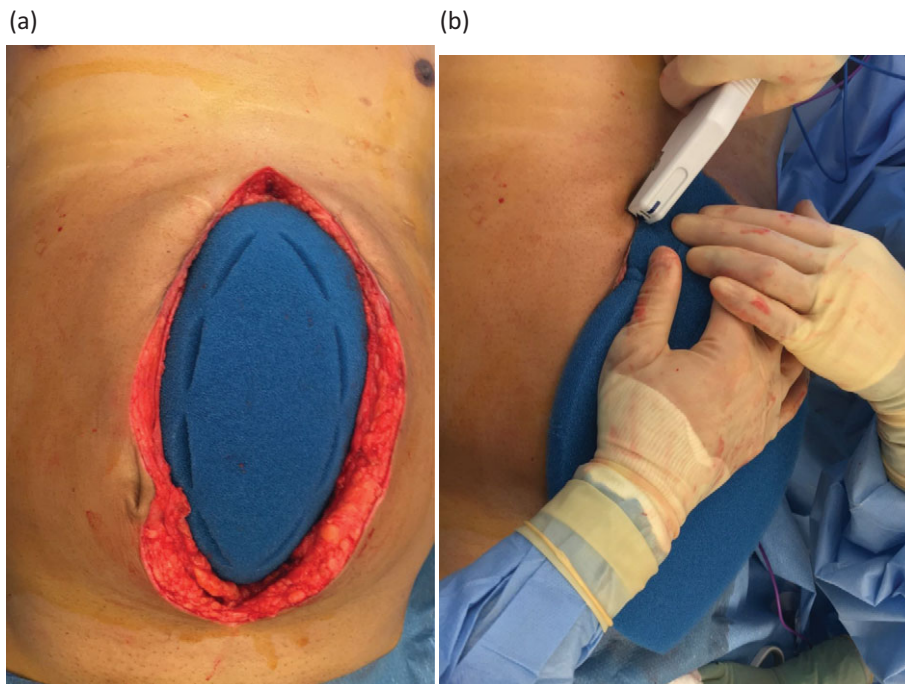


Figure 23.8 Application of ABThera for temporary abdominal closure. Placement of the first layer of fenestrated foam, under the peritoneum (a) and the second layer between the edges of the abdominal wound (b).

- The third layer consists of a similar foam placed over the previous layer, between the fascia edges.
- The fourth layer is a semi-occlusive adhesive drape placed over the foam.

A 1-cm diameter opening is then created in the adhesive drape, exposing the underlying foam, and an interface pad and tubing are placed over the opening and sealed. The

negative pressure collapses the foam, applying medial traction to the wound, and removes intra-abdominal fluid that is then collected in the removable canister.

Dressing changes are usually done every 2–3 days, usually in the OR, with serial closure of the abdominal wall. The optimal negative pressure is 125 mmHg. However, in the presence of bleeding, a lower pressure (25–50 mmHg)

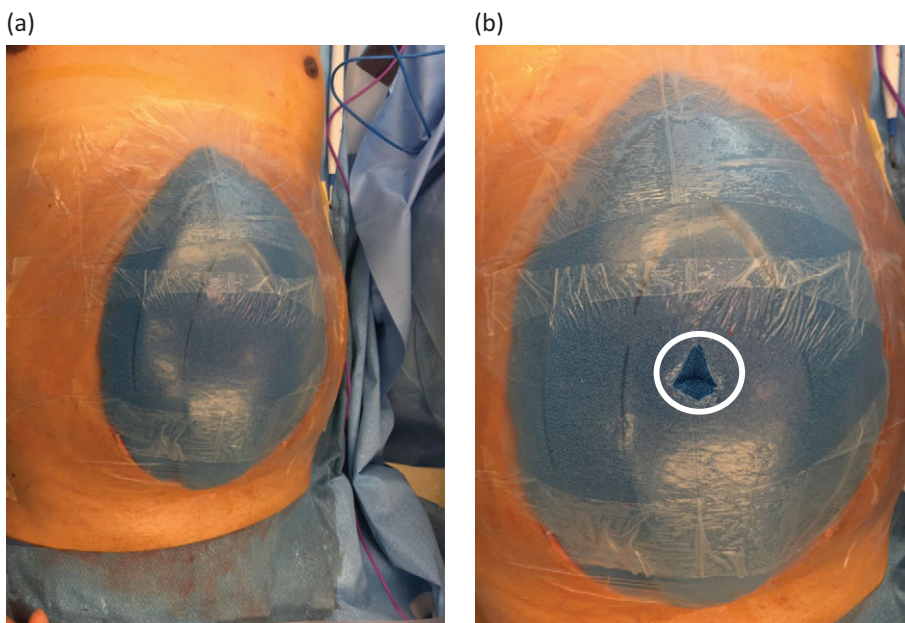


Figure 23.9 Application of ABThera for temporary abdominal closure: A semi-occlusive adhesive drape, placed over the foam (a). A 1-cm diameter opening (circle) is then created in the adhesive drape, exposing the underlying foam (b). Application of ABThera for temporary abdominal closure. An interface pad with a tubing system is placed over the opening on the adhesive drape (c) and the tube is connected to the pump (d).

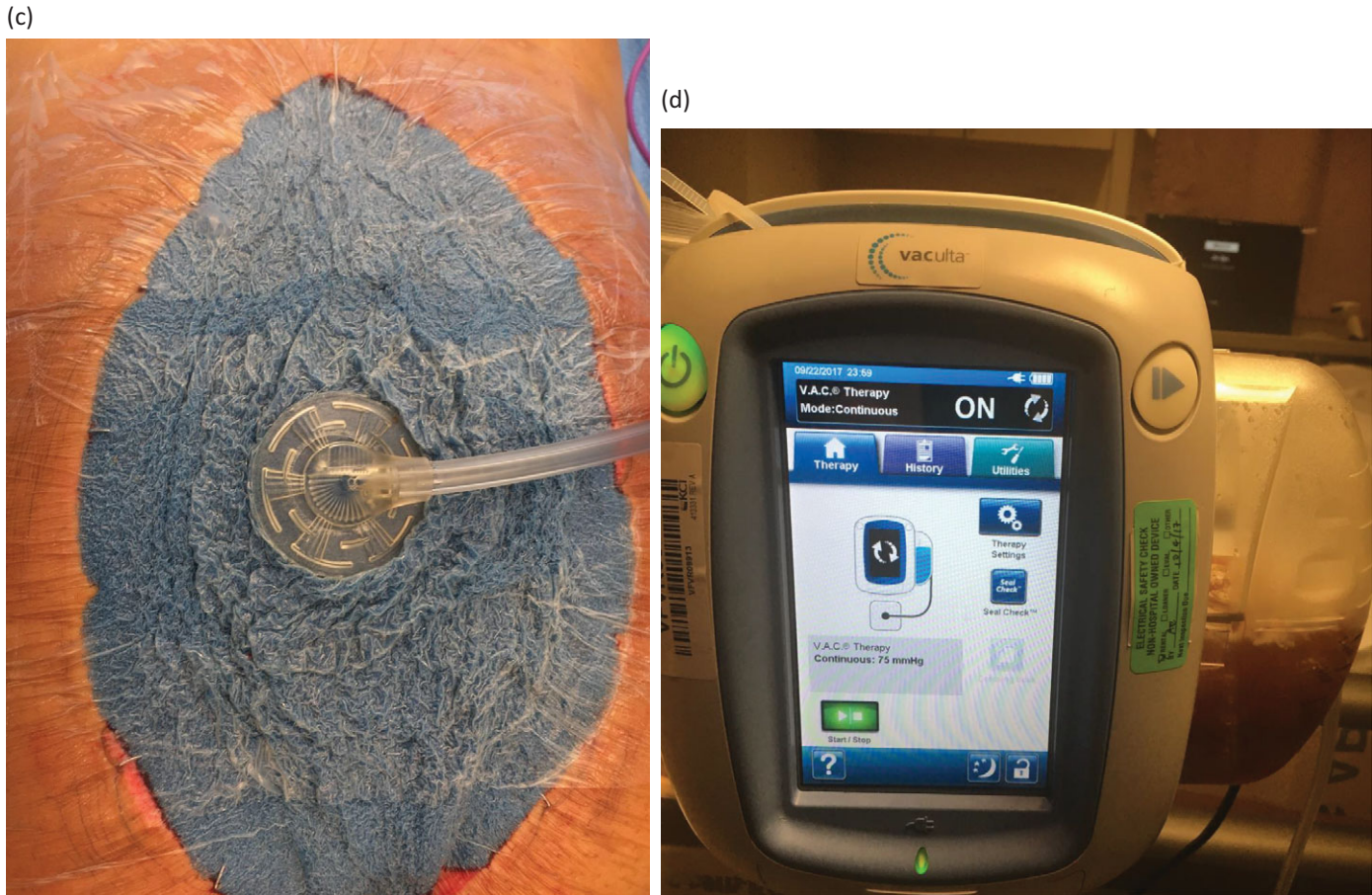


Figure 23.9 (cont.)

should be used initially, due to the increased risk of bleeding associated with negative pressure therapy. Higher pressures can be applied after complete hemostasis is assured.

Caution with NPT

- In cases with incomplete hemostasis, application of high negative pressure may aggravate bleeding. In these cases, an initial low negative pressure is advisable. If large amounts of blood are seen in the canister of the vacuum pump, the negative pressure should be immediately discontinued and the patient returned to the operating room for re-exploration and bleeding control.
- IAH may occur in rare cases with temporary abdominal wall closure with NPT dressing. The bladder pressure should be monitored routinely during the first few hours of negative-pressure dressing application.
- The foam should never be in direct contact with the intestine because of the risk of fistula formation.

Definitive Fascia Closure

- Early, definitive closure of the abdomen, within less than 5–7 days, reduces the complications associated with the open abdomen. The closure should be achieved without tension or risk of recurrence of IAH.
- Primary fascia closure may be possible in many cases within a few days of the initial operation, and should be considered when all intra-abdominal packing has been removed, any residual infection is cleared, and the bowel edema subsides.
- In some patients, early definitive fascial closure may not be possible because of persistent bowel edema or intra-abdominal sepsis. In these cases, progressive closure should be attempted at every return to the operating room for dressing change, by placing a few interrupted sutures at the top and bottom of the fascia defect. Various fascia traction systems in combination with NPT may be used to facilitate closure.
- In patients with persistent large fascial defects, definitive reconstruction should be considered, using synthetic or

(a)



(b)

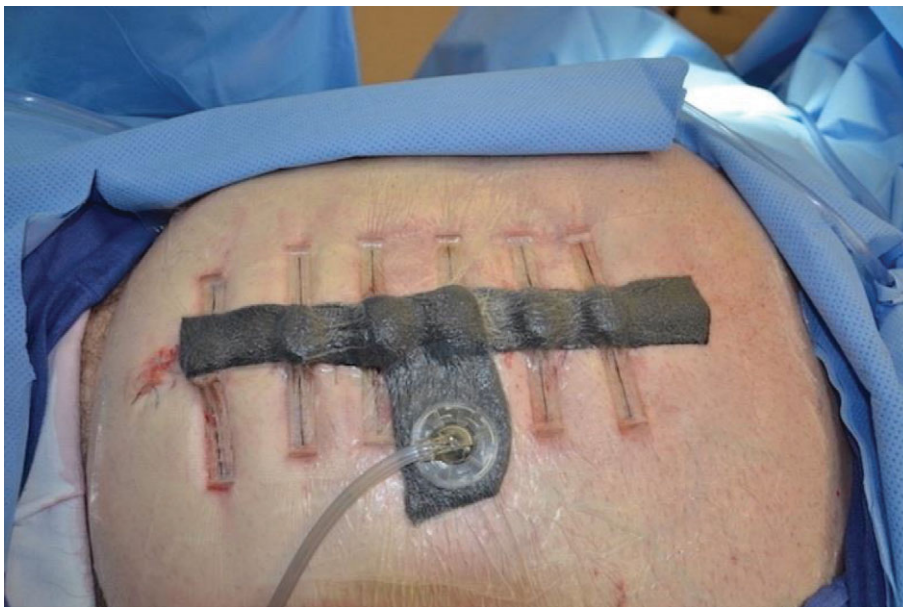


Figure 23.10 Progressive definitive fascial closure for the difficult to close abdomen. Placement of a few interrupted sutures at the top or the bottom of the fascia defect at every return to the operating room **(a)**. Fascia traction systems can be used in combination with negative pressure therapy to facilitate closure **(b)**.

biological meshes or sheets, or autologous tissue transfer with component separation.

Tips and Pitfalls

- Consider early damage control, before the patient becomes “in extremis.” The timing of DC is critical in determining the outcome.
- Interventional radiology is an important component of DC. Consider going to the angiography suite straight from the operating room or utilize a hybrid operating room if available.
- Postoperative continuous bleeding after DC must be examined in the operating room immediately. Do not assume that it is coagulopathic bleeding!
- The type of negative pressure therapy used for TAC can influence outcomes.
- In the presence of bleeding, avoid using high negative pressure therapy.
- In applying ABthera or any other NPT, make sure that the foam does not come into direct contact with the bowel because of the risk of fistula formation.

Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA)

Elizabeth R. Benjamin and Kazuhide Matsushima

General Principles

- Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) is a compliant, endovascular balloon designed to occlude the thoracic or lower abdominal aorta in hemorrhagic shock, for temporary control of bleeding in the abdomen or pelvis.
- The REBOA catheter is placed through a sheath in the right or left common femoral artery, accessed using anatomic landmarks, ultrasound guidance, or with open surgical technique. The balloon is then inflated in the thoracic or abdominal aorta, effectively acting as a minimally invasive aortic cross-clamp.
- The procedure for placing a REBOA takes only a few minutes.
- REBOA is ideally suited for hypotensive patients with abdominal or pelvic bleeding and can be placed in the emergency room, intensive care unit, or the operating theater.
- REBOA balloon placement can be guided and confirmed using external landmarks, X-ray, fluoroscopy, or ultrasound. Balloon inflation volumes are titrated based on invasive blood pressure monitoring, haptic feedback, and imaging.
- REBOA is contraindicated in patients with intrathoracic, neck, or facial bleeding, in cases with high suspicion for blunt thoracic aortic injury, and in patients in cardiac arrest.
- Aortic occlusion is a temporary, resuscitative measure and should be considered a transition to definitive care. After inflation, the patient should be immediately transported to the operating room or the interventional suite for definitive management of their traumatic injuries.
- REBOA balloon inflation results in distal ischemia and as such, occlusion times should be minimized.

Surgical Anatomy

- REBOA placement requires access to the common femoral artery. It is critical that the sheath access point is above the common femoral artery bifurcation in order to minimize the risk of distal limb ischemia.

- For the purposes of REBOA placement, the thoracic and abdominal aorta is divided into three zones (Figure 24.1).
 - Zone 1: left subclavian artery to the diaphragm
 - The descending aorta passes through the diaphragm at T12–L1.
 - The external landmark for balloon inflation in Zone 1 is the mid sternum.
 - Zone 2: celiac artery to renal artery. Inflation in Zone 2 should be avoided due to risk of damage to the visceral and renal vessels, especially in patients with existing atherosclerotic disease.

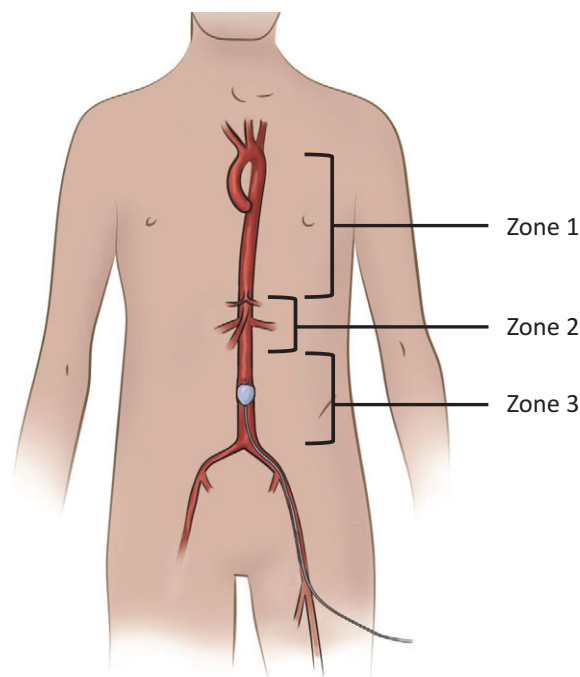


Figure 24.1 For the purposes of REBOA placement, the aorta is divided into three anatomic zones. Zone 1 spans distal to the left subclavian artery to the level of the diaphragm and is ideal for abdominal or pelvic bleeding. Zone 3 describes the zone of occlusion for pelvic and perineal bleeding and spans the area distal to the renal vessels and above the aortic bifurcation. Zone 2 is the region of the visceral and renal vessels, and REBOA inflation in this zone should be avoided.

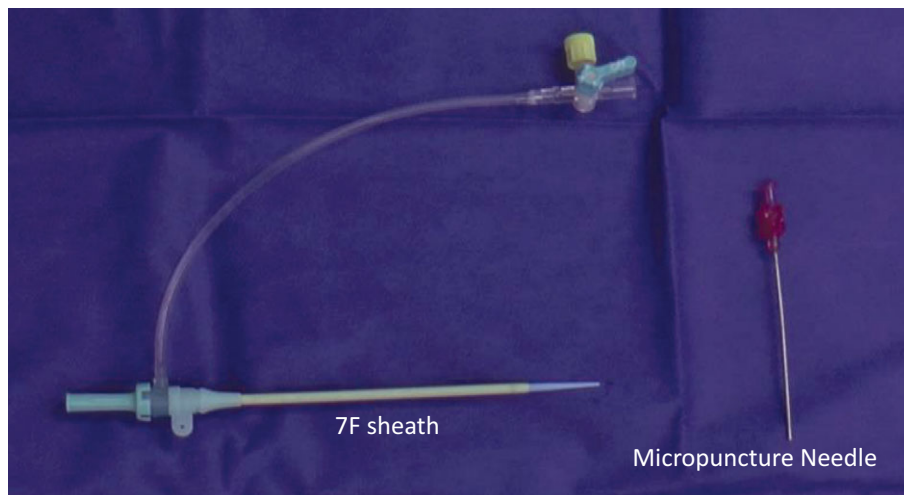


Figure 24.2 Access to the common femoral artery is obtained using a percutaneous or open technique. Depending on the catheter system available, a 7F or larger sheath in the common femoral artery is used for introduction of the REBOA catheter.

- Zone 3: renal artery to aortic bifurcation
 - The renal arteries branch at the level of L2 and the aorta bifurcates into the right and left common iliac arteries at L4–L5.

Special Instruments

- There are several commercially available balloons that can be used for endovascular occlusion of the aorta. The currently available devices are used with a 7–12F introducer sheath (Fig. 24.2). Wire-based and wireless catheter kits are available and balloon inflation volumes vary based on manufacturers' guidelines. It is imperative that the provider is familiar with and trained on the device available within the home institution, as there is wide variation in insertion technique and inflation volumes.
- Additional materials for REBOA insertion are modified based on the catheter used and include additional wires, dilators, syringes, and arterial monitoring devices.
- Current wireless catheter systems require a 10–30 cm³ syringe for balloon inflation, an additional 10 cm³ syringe to flush the arterial port, and ideally an arterial line set up for ongoing blood pressure monitoring once the catheter is in place.
- A portable ultrasound machine with high-frequency probes (optional).

- Basic open surgical tray should be available in case open cut-down is required to obtain femoral access.
- Diluted injectable contrast media is instilled through the balloon port of the REBOA catheter.
- An invasive arterial line and monitoring system is ideally in place to guide placement, occlusion, and postocclusion management (optional).

Insertion Techniques

- The patient is placed in the supine position, the hip abducted slightly.
- Bilateral groins are prepped and draped. Either groin may be used for REBOA access.

Insertion of an Introducer Sheath

- The arterial sheath is placed in the common femoral artery, above the level of the bifurcation to allow adequate vessel diameter to accommodate the necessary sheath size and to minimize distal ischemic complications.
- The femoral artery can be accessed approximately 2 cm below the inguinal ligament, approximately equidistant between the pubic symphysis and the anterior superior iliac spine. The use of bedside ultrasound can improve accuracy and speed of access (Fig. 24.3a, b). If bedside ultrasound is unavailable, open groin access to the arterial system is recommended.

(a)



Figure 24.3 (a) Access to the common femoral artery can be confirmed using ultrasound guidance. (b) Entry into the common femoral artery above the bifurcation is imperative for safe placement of the arterial sheath. Wire entry into the artery can be used to confirm appropriate placement of arteriotomy.

(b)



- The size of an introducer sheath should be selected based on the size of the REBOA catheter to be inserted. A 7F sheath can accommodate several currently available commercial catheters.
- For percutaneous access, the common femoral artery is accessed using a micropuncture needle or a standard arterial line kit.
- Once arterial backflow is confirmed, a guidewire is advanced carefully and an introducer sheath is inserted using the Seldinger technique (Fig. 24.4). Alternatively, an arterial line may be placed and later upsized to a sheath to accommodate REBOA placement.



Figure 24.4 Using a standard Seldinger technique, an arterial sheath may be placed.

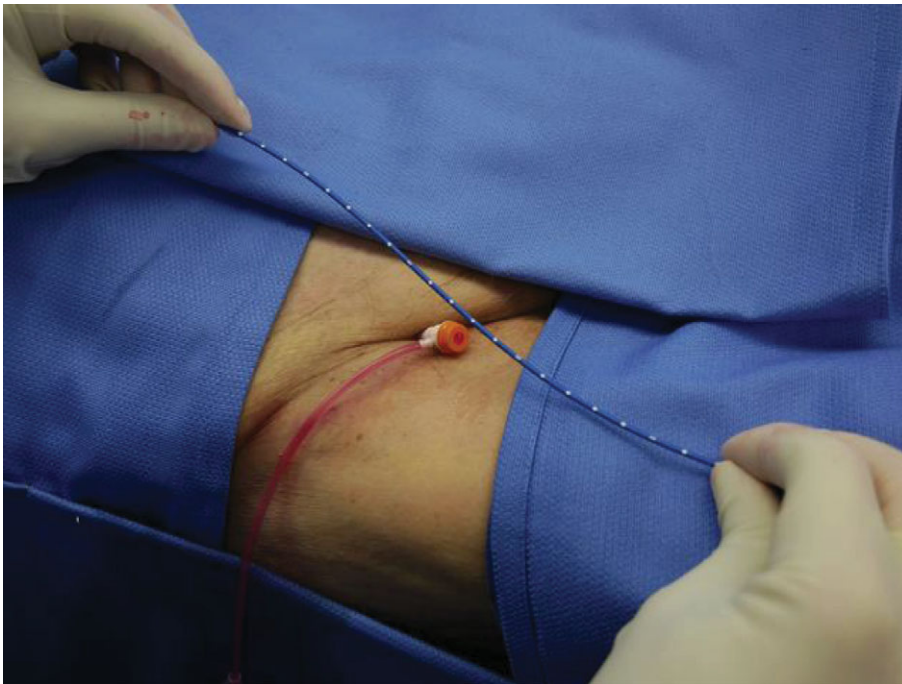


Figure 24.5 Using external landmarks, the balloon placement is approximated prior to insertion.

Insertion and Positioning of a REBOA Catheter¹

- Prior to insertion, the catheter should be measured to estimate the distance to the desired landing zone (Fig. 24.5).
 - Zone 1 placement: the desired insertion distance is estimated placing the balloon at the mid sternum and measuring the distance to the insertion site.
 - Zone 3 placement: external landmarks are less reliable and it is recommended to use imaging to guide
- The ER-REBOA™ device has a P-curved, flexible tip, a compliant balloon, has centimeter markings for external measurement, radiopaque markers above and below the balloon limits, and an arterial port for pressure monitoring above the balloon (Fig. 24.6). Inflation volumes typically range from 2–8 cm³.

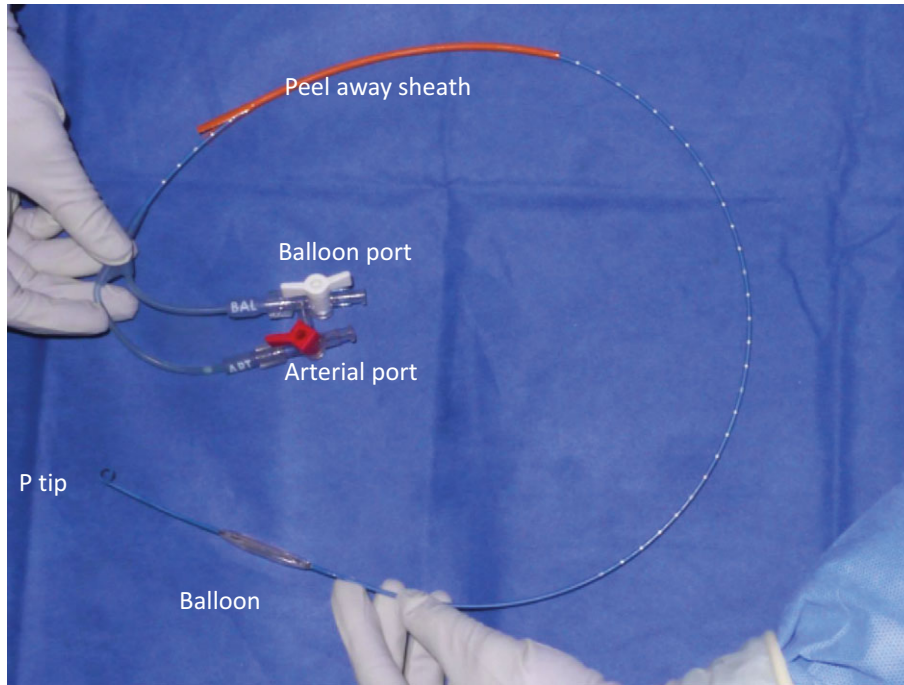


Figure 24.6 Several balloons for endovascular occlusion of the aorta are available commercially. Pictured is the ER-REBOA™ system, which is a wireless catheter with an arterial monitoring port included. The catheter is centimeter-marked for accurate measurement. There is a radiopaque marker at the upper and lower aspects of the balloon to facilitate balloon placement.

¹ For the purposes of this chapter, the procedure is described using the 7F Prytime ER-REBOA™ catheter. Note manufacturers' instructions when applying and modifying the steps for use.



Figure 24.7 The three-way stopcock on the balloon port is closed under negative pressure to ensure that any residual air in the balloon is extracted prior to insertion.

- Before inserting a REBOA catheter, the arterial port should be flushed and the balloon completely deflated. It is unnecessary to test the balloon, and inflation of the balloon prior to insertion is not recommended (Fig. 24.7).
- The orange peel-away sheath is carefully corkscrewed over the balloon and P-tip to prepare the catheter for insertion.

The orange peel away is inserted into the arterial sheath approximately 1 cm or less to allow passage of the P-tip and the balloon past the valve of the sheath (Fig. 24.8). Note that the orange peel-away is *not* designed to insert fully into the sheath, and attempts to introduce it further will be unsuccessful.



Figure 24.8 The peel-away sheath straightens the P-tip and protects the catheter balloon. It is inserted only less than 1 cm into the sheath to allow passage of the balloon past the valve. Once this is accomplished, the peel-away sheath is removed.

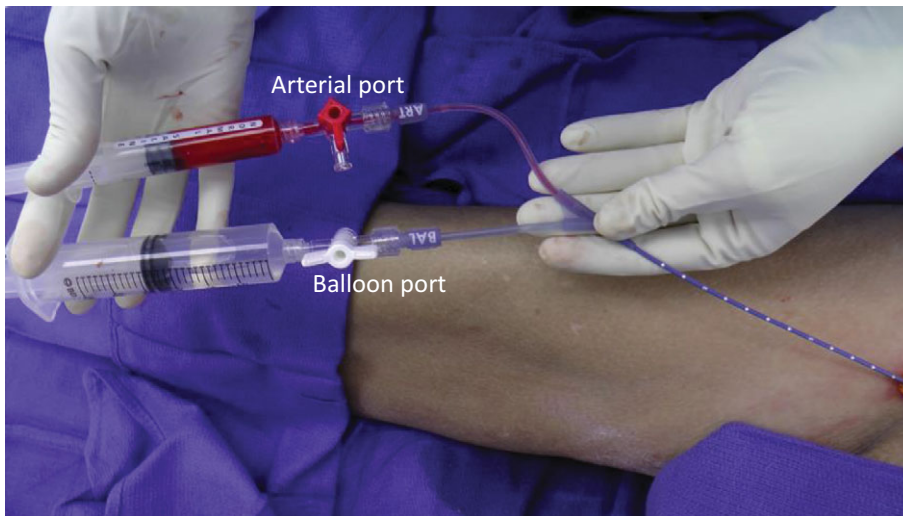


Figure 24.9 The arterial port is flushed and used for continuous arterial pressure monitoring. The balloon is inflated using diluted contrast and balloon placement and morphology are confirmed by X-ray or fluoroscopy.

- The REBOA catheter is inserted through the femoral artery. Once the balloon has passed the valve of the sheath, the peel-away can be removed.
- The REBOA catheter is advanced to the premeasured depth. The catheter should not be advanced if there is any resistance.

Inflation of the Balloon

- The position of the balloon should be confirmed by imaging prior to inflation. X-ray and fluoroscopy are the most common methods of position confirmation. If imaging is not immediately available, proceed with inflation based on external landmarks.
- Once the position is confirmed, the balloon is inflated with diluted contrast (Fig. 24.9).
- Balloon inflation volume ranges are defined by the manufacturer and should be reviewed prior to insertion. Actual inflation volume, within this range, is best determined real-time using invasive blood pressure measurements, haptic feedback from the balloon, and palpation of the femoral pulse. Balloon placement and morphology can be evaluated with X-ray. Overinflation should be avoided, as it can result in intimal damage or balloon rupture.
- Time of inflation should be documented and ischemia time monitored. Frequent pulse and compartment checks should be performed distal to the insertion site to monitor for limb ischemia and compartment syndrome.
- Once the balloon is inflated and the position confirmed, secure the catheter in place to prevent balloon migration (Fig. 24.10).

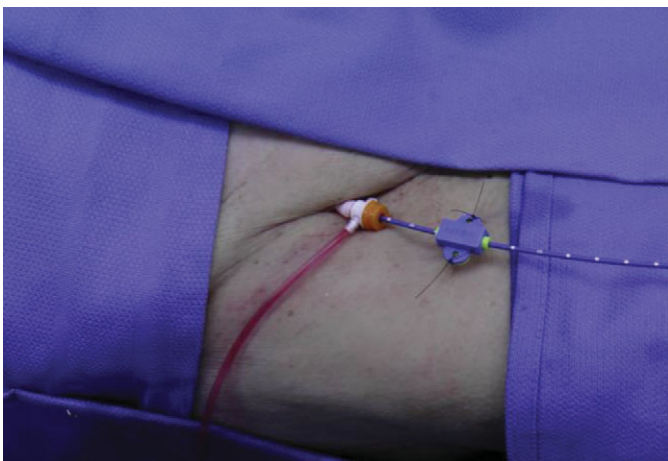


Figure 24.10 Once position is confirmed, the catheter is fixed in place to avoid migration.

Removal

- Prior to REBOA removal, slowly deflate balloon entirely.
- The REBOA catheter itself should be immediately removed from the aorta once the balloon is deflated. The catheter is thrombogenic and prolonged indwelling can increase the risk of thrombotic complications.
- The arterial sheath should be removed as early as possible once REBOA is no longer needed. Without heparin infusion, the sheath is prone to clot formation and risk of distal emboli is increased. The infusion port of the sheath should be aspirated prior to removal to confirm lack of clot formation on the catheter tip.
- For 7F sheaths, the catheter can be removed manually with pressure held at the insertion site for 30 minutes. If there is any concern for ongoing bleeding or other local complication, immediate open groin exploration is recommended.
- Larger sheaths should be removed under direct visualization and the arteriotomy repaired using open technique.
- Arterial ultrasound should be performed after 24 hours to assess for possible pseudoaneurysm at the insertion site.

Complications

- REBOA inflation is designed to occlude aortic blood flow distal to the level of inflation. Prolonged Zone 1 inflation can result in visceral, renal, and lower extremity ischemia, resulting in bowel ischemia, acute kidney injury, and muscle compartment syndrome or limb loss.
- Over inflation of the balloon or inflation outside of the recommended landing zones can result in intimal damage and arterial injury.
- Especially in patients with pre-existing disease, arterial trauma, or tortuous vessels, passage of a REBOA catheter can result in dissection or vessel injury.
- Complications related to arterial access can be initially innocuous, but ultimately result in significant morbidity.
 - Although less common with the lower-profile catheters, placement of the 7F sheath can cause significant local trauma, including arterial transection, dissection, or thrombosis and embolization, all of which can result in distal ischemia and limb loss. Placement of the sheath in the common femoral artery, away from the bifurcation, minimizes this risk.
 - Ischemia and reperfusion injury increase the risk of extremity compartment syndrome.
 - Hematoma or pseudoaneurysm at the insertion site can be detected by a post-removal vascular ultrasound study.

Tips and Pitfalls

- The most complicated part of REBOA catheter placement is patient selection, and knowing when to use this resuscitative technique.
 - REBOA inflation results in an increase in pressure above the level of inflation. For this reason, it is not recommended to inflate the balloon in cases with thoracic, neck, or facial hemorrhage. Inflation in these cases may result in exacerbation of hemorrhage.
 - In cases of cardiac arrest, open thoracotomy remains the standard of care, as it is both a resuscitative and potentially therapeutic procedure.
 - REBOA should never be placed in cases of suspected blunt thoracic aortic injury. Attempted placement may result in worsening of the injury or immediate rupture.
- It is imperative that the arterial sheath is placed in the common femoral artery. Distal placement in the superficial femoral artery or at the bifurcation can lead to serious complications including limb ischemia.
- Arterial injury or occlusion can occur with sheath placement. It is imperative to perform frequent vascular checks distal to the insertion site. Vascular and compartment checks should be continued for at least 24 hours post removal and a vascular ultrasound should be performed to assess for pseudoaneurysm at the insertion site. The provider should be prepared to perform open arterial exploration and repair, embolectomy, or bypass in the event of an injury and lower extremity fasciotomies in the event of compartment syndrome.
- When possible, imaging should be obtained prior to REBOA inflation to confirm balloon placement. Errant balloon placement can lead to serious complications (Fig. 24.11).



Figure 24.11 Balloon inflation in the common iliac artery (arrow), visible through a left retroperitoneal dissection.

- Continuous arterial blood pressure monitoring is recommended during balloon inflation to guide inflation volumes. If available, X-ray confirmation of balloon morphology is recommended.
- Balloon inflation volumes differ based on catheter used and hemodynamics of the patient. Extreme care should be taken to avoid overinflation of the REBOA balloon.
- Catheter migration is common, especially with the lower-profile catheters. Fixation and frequent confirmation of catheter placement at the insertion site is recommended.
- Partial REBOA describes the partial inflation of the occlusion balloon. Currently, this is achieved by active titration of the balloon volume by the provider based on real-time variations in blood pressure readings in conjunction with active ongoing resuscitation.
- REBOA is designed as a temporary occlusion device and should be used as a bridge to definitive care. Occlusion times should be minimized and the provider should be prepared for the consequences of reperfusion physiology when the balloon is deflated.

Gastrointestinal Tract

Morgan Schellenberg, Lisa L. Schlitzkus, and Kenji Inaba

Special Surgical Instruments

- Trauma laparotomy set
- Fixed abdominal retractor, e.g., Bookwalter
- Adequate lighting including a headlamp
- Temporary abdominal closure devices should be available, if needed

Positioning

- The patient should be positioned in the standard trauma position: supine with the arms abducted to 90°, and prepped from the neck to the knees.
- If there is concern for rectal injury and the patient is hemodynamically stable, lithotomy position should be considered.

Incisions

- A midline laparotomy incision is the standard trauma incision for abdominal exploration and allows exposure of the gastrointestinal (GI) tract.
- A left thoracotomy may also be required to repair extensive gastro-esophageal junction injuries.
- A right subcostal incision may be needed for exposure of the retrohepatic veins.

Stomach

Surgical Anatomy

- The GE junction is the intra-abdominal portion of the esophagus and the cardia of the stomach.
- The fundus of the stomach overlies the spleen. These two structures are connected by the gastrosplenic ligament, which contains the short gastric arteries.
- The blood supply to the stomach is provided by the left and right gastric arteries in the lesser curvature and the left and right gastroepiploic arteries in the greater curvature.
- The blood supply of fundus of the stomach is provided by the short gastric arteries, which arise from the distal splenic artery.

General Principles

- Regardless of the mechanism of injury, both the anterior and posterior walls of the stomach must be completely visualized in order to exclude injury.
- The posterior stomach is exposed by entering the lesser sac through the gastrocolic ligament. The stomach is retracted cephalad and the transverse colon is retracted caudally to facilitate this maneuver. After division of the gastrocolic ligament, insertion and then slow withdrawal of two wide malleable retractors into the lesser sac allows inspection of the posterior wall of the stomach and the body of the pancreas.

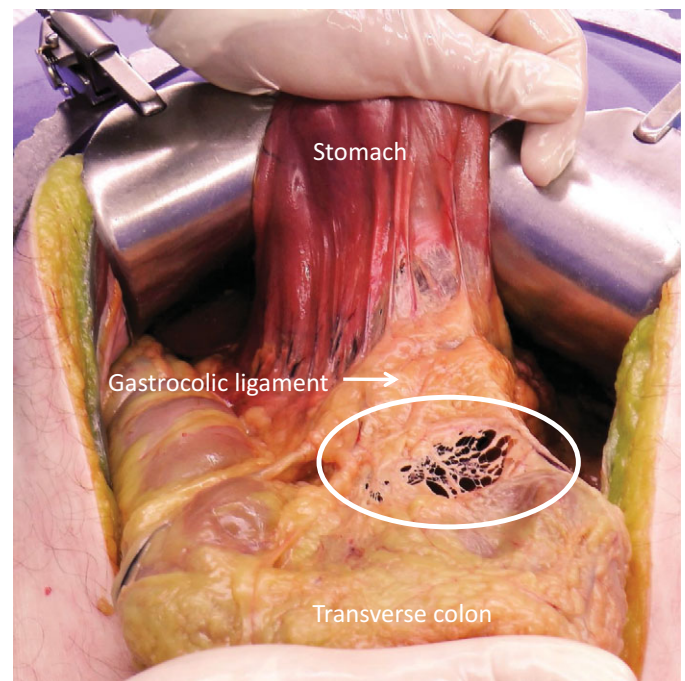


Figure 25.1 Entry in the lesser sac: The stomach is retracted cephalad and the transverse colon is retracted caudally and the avascular plane (circle) of the gastrocolic ligament is divided.

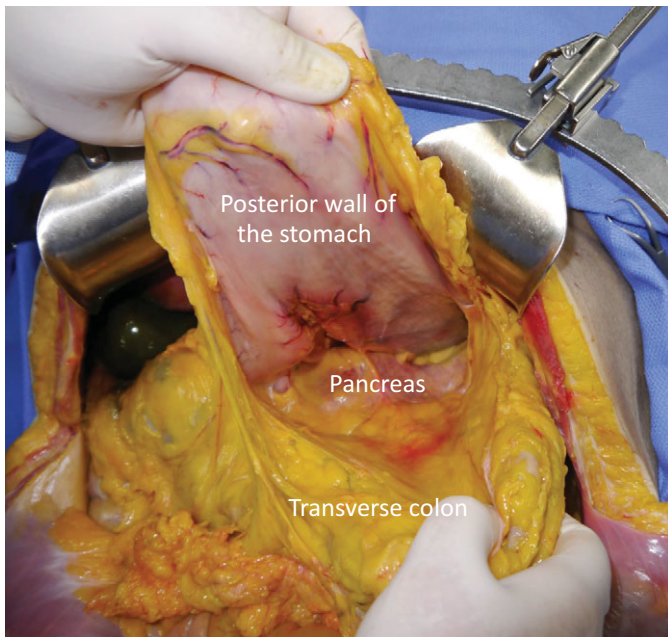


Figure 25.2 After division of the gastrocolic ligament, elevating the stomach with downward traction of the transverse colon provides a good view of the posterior wall of the stomach and the pancreas.

- Most injuries to the stomach can typically be managed with primary repair, as a one- or two-layer suture repair or as a stapled wedge resection of the injury.

Gastroesophageal Junction Injuries

- The gastroesophageal junction is an anatomically difficult area and its exposure may be challenging, especially in overweight patients. The exposure can be improved if the patient is placed in the reverse Trendelenburg position, a fixed retractor is placed and a good headlight is used.
- The first step in exposing the gastroesophageal junction is to divide the left triangular ligament and mobilize the left lobe of the liver. The abdominal esophagus is palpated (a previously placed nasogastric tube helps identify the esophagus), and the peritoneum over the esophagus is incised. The abdominal aorta is posterior and to the left of the esophagus and the dissection should be between these two structures. A Penrose drain is placed around the esophagus for retraction. Division of the left crus of the diaphragm, at the avascular 2 o'clock position, provides additional exposure of the distal thoracic esophagus.
- Most gastroesophageal junction injuries can be managed with primary repair, after debridement of any devitalized tissues. The repair should be tension-free and should be buttressed with omentum or gastric fundus wrap.

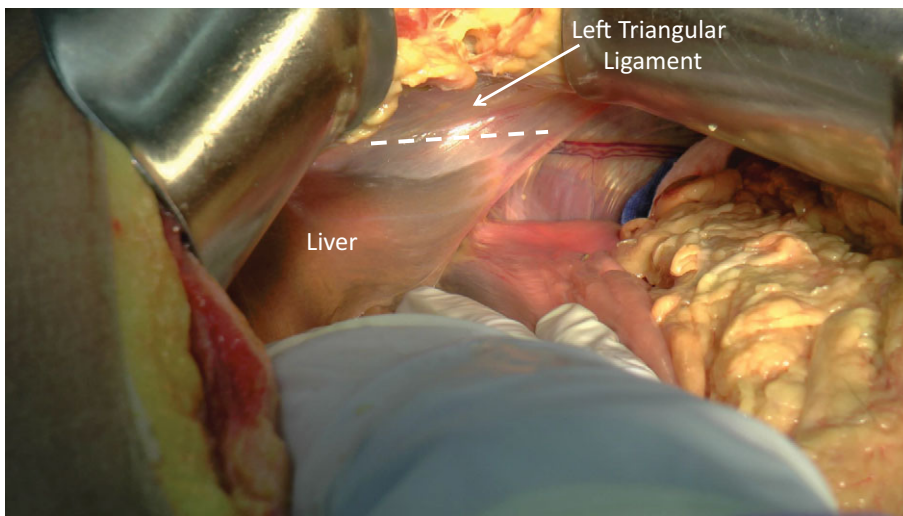
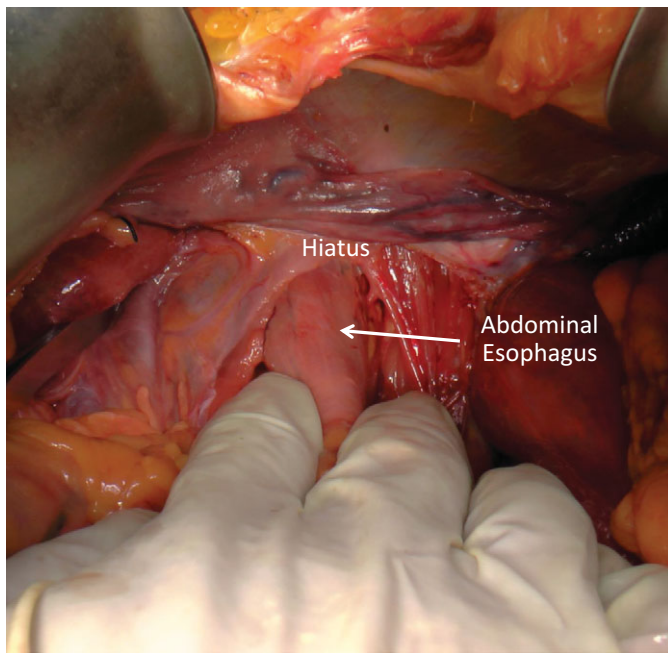
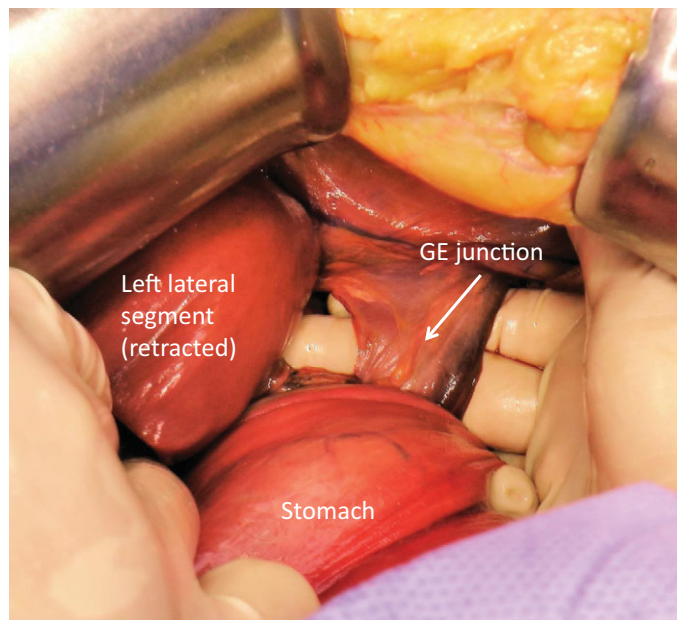


Figure 25.3 The first step for the exposure of the gastroesophageal junction is mobilization and medial retraction of the left lobe of the liver. The left triangular ligament is divided (interrupted line).

(a)



(b)



(c)

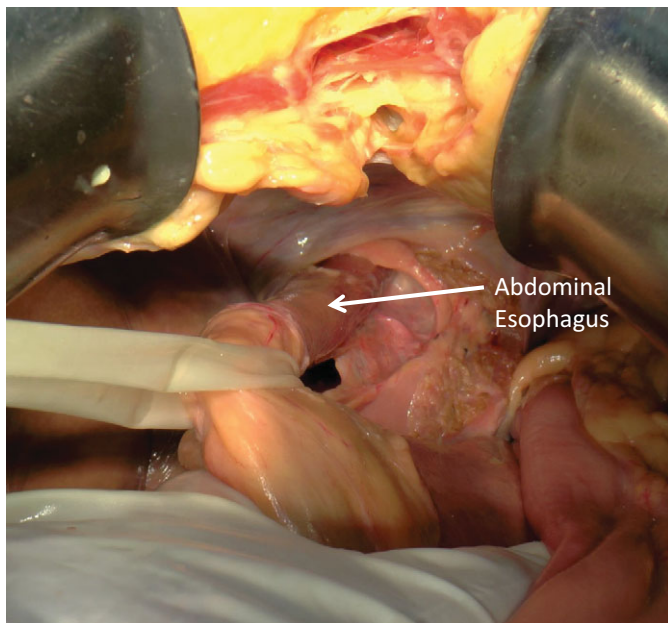
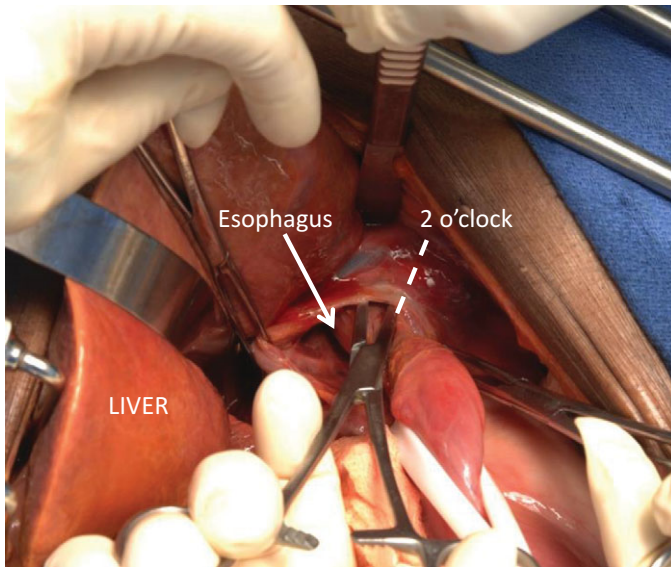


Figure 25.4 (a) Exposure of the abdominal esophagus after dissection of the overlying peritoneum. (b) Finger dissection between the abdominal esophagus and the aorta and isolation of the esophagus. (c) After the esophagus is circumferentially dissected at the gastroesophageal junction, a Penrose drain is positioned around it for traction.

(a)



(b)

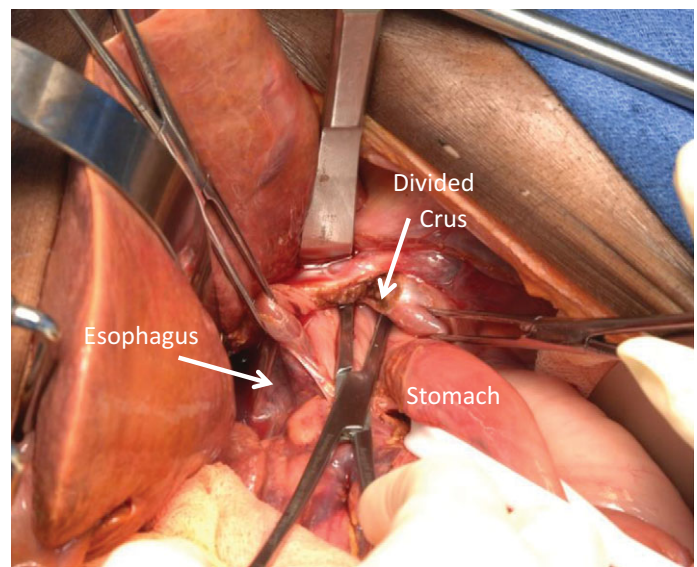
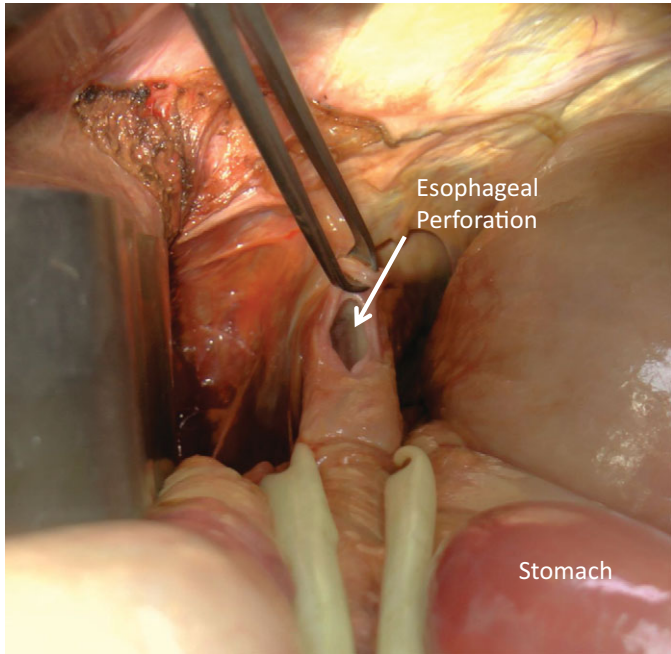


Figure 25.5 (a, b) Division of the diaphragmatic crus at the 2 o'clock position provides additional exposure of the esophagus.

(a)



(b)

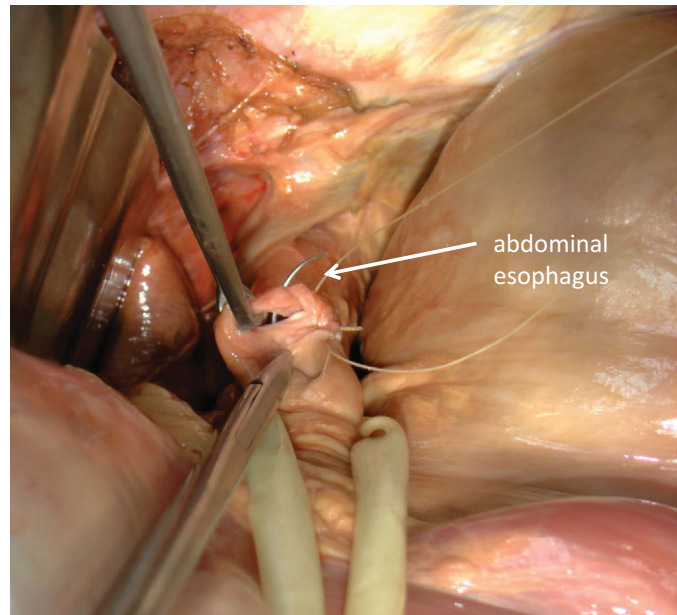
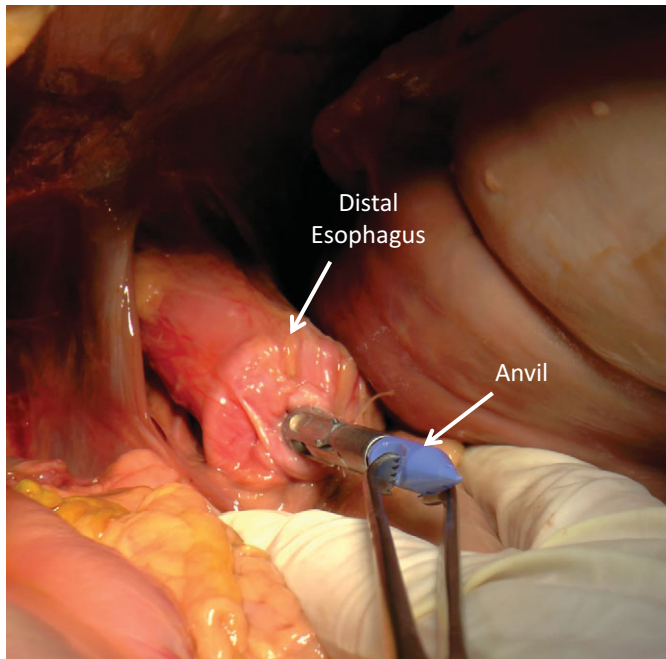


Figure 25.6 (a) Most injuries can be repaired primarily after debridement of devitalized tissues. Most esophageal injuries can be repaired primarily. After debridement of devitalized tissues (a), primary repair is performed (b).

- Destructive injuries may require local resection and a stapled or hand-sewn esophagogastric anastomosis, buttressed with omentum or gastric fundus wrap.

(a)



(b)

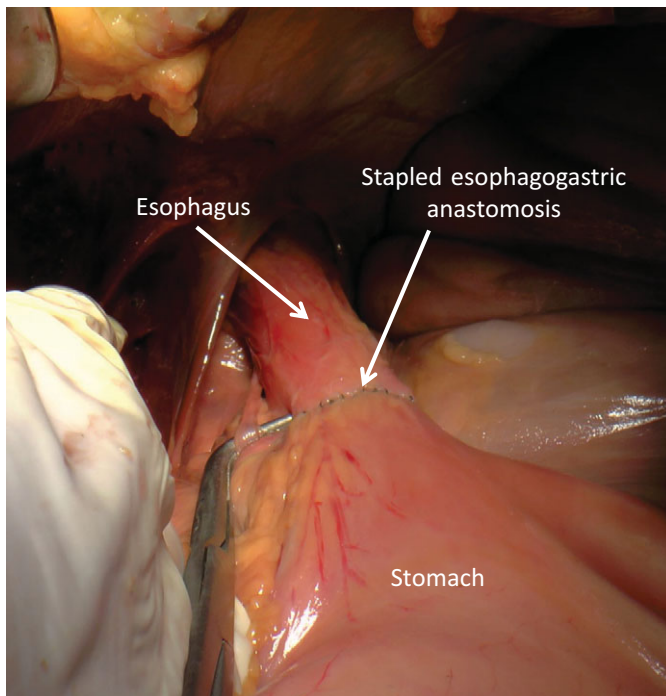


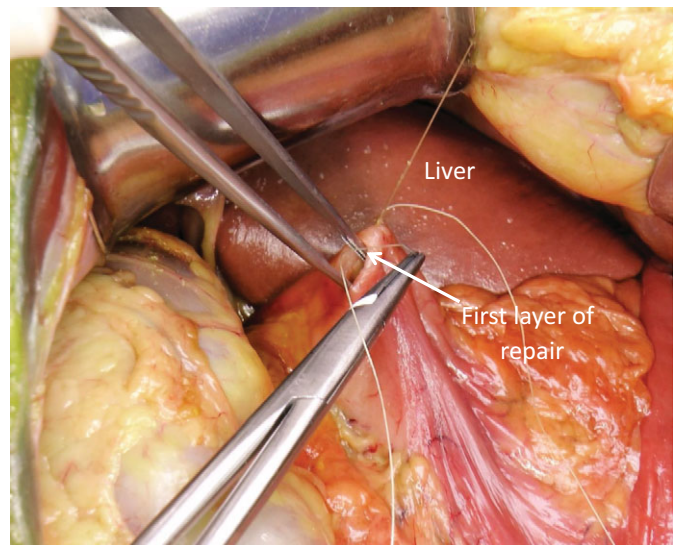
Figure 25.7 (a) EEA stapled esophagogastric anastomosis. (b) Completed stapled esophagogastric anastomosis.

- In severe gastroesophageal junction injuries and in the presence of associated major vascular injuries and hemodynamic instability, damage control with bleeding and contamination control should be considered at the index operation followed by reconstruction 24–48 hours later. Delayed reconstruction of the gastroesophageal junction may require a left thoracotomy, in addition to laparotomy, and can be completed with a hand-sewn or stapled anastomosis using an EEA stapler.
- In complex gastroesophageal junction injuries, a jejunal feeding tube should be considered. Alternatively, a post-pyloric nasogastric feeding tube can be placed intraoperatively to allow enteral feeding in case of any anastomotic leak.

Pyloric Injuries

- Primary repair of simple pyloric injuries can be accomplished with pyloroplasty, to avoid stenosis.

(a)



(b)

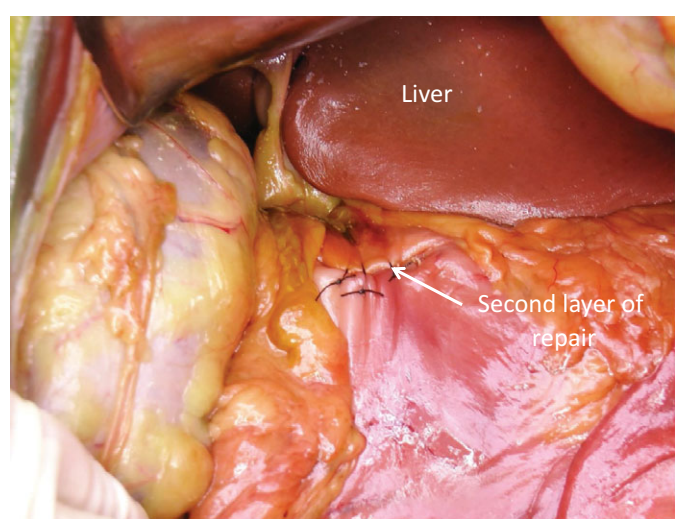


Figure 25.8 (a, b) Primary repair of simple pyloric injuries can be accomplished with pyloroplasty, to avoid stenosis. The repair can be done in one or two layers.

- More complex pyloric injuries may require antrectomy. Options for reconstruction include Billroth I, Billroth II, or Roux-en-Y.
- A gastrojejunostomy should be considered in complex pyloric repairs.

Tips and Pitfalls

- The anterior and posterior aspects of the stomach must always be inspected for injury.
- Hematomas due to penetrating trauma along the gastric wall, particularly along the curvatures, must be opened in order to exclude underlying injury.
- Most gastroesophageal junction injuries can be approached through the abdomen alone, with proper mobilization and division of the left crus of the diaphragm. The repair or anastomosis can be buttressed with omentum or a gastric fundus wrap.

Small Intestine

Surgical Anatomy

- The blood supply and venous drainage to the jejunum and ileum are from branches of the superior mesenteric artery (SMA) and tributaries of the superior mesenteric vein (SMV), respectively. The SMV is to the right and anterior to the SMA. The confluence of the SMV and the splenic vein, which occurs behind the neck of the pancreas, is the origin of the portal vein.

General Principles

- Small bowel perforation following blunt trauma usually involves the antimesenteric border. Another type of trauma is a bucket handle injury, following high-speed deceleration injuries, causing a mesenteric tear and possible intestinal devascularization.



Figure 25.9 Bucket handle injury of the mesentery due to deceleration forces. Note the ischemic necrosis of the bowel.

- Intraoperative assessment of the small bowel must proceed methodically and carefully in order to avoid missing injuries. The entire circumference of the small bowel and mesentery from the ligament of Treitz to the ileocecal valve must be examined.
- The entire small bowel should be evaluated before deciding about primary repair or resection and anastomosis. If multiple small bowel injuries are identified in close proximity, resection of the injured segment may be a more reasonable intervention than multiple primary repairs.
- Primary repair of an enterotomy should always be performed after debridement of devitalized tissues and in a transverse orientation to avoid stenosis.
- The selection of hand-sewn vs. stapled intestinal anastomosis is largely a decision based on surgeon preference.
- Even during damage control surgery, bowel discontinuity should be avoided if at all possible, because it creates complete intestinal obstruction, which may aggravate ischemia and bacteria or toxin translocation.

Tips and Pitfalls

- Bowel wall hematomas, especially due to penetrating trauma, should be unroofed to rule out underlying injury.
- Before planning repair or resection of a small bowel injury, ensure the entirety of the small bowel has been inspected, from the ligament of Treitz to the ileocecal valve, to exclude additional small bowel injuries. If multiple enterotomies are present, a single resection is preferable to multiple primary repairs or resections.
- Although patients tolerate removal of a significant length of small bowel, preservation of a minimum of 100 cm should be attempted, whenever possible, to avoid short bowel syndrome.
- Avoid leaving bowel in discontinuity, if at all possible.

Colon

Surgical Anatomy

- The blood supply to and venous drainage of the ascending colon is from the ileocolic and right colic arteries and veins, terminal branches of the SMA and SMV.
- The blood supply to and venous drainage of the transverse colon is from the middle colic artery and vein, which are also terminal branches of the SMA and SMV.
- The descending colon is supplied and drained by the left colic artery and vein, terminal branches of the IMA and IMV.
- The blood supply and drainage of the sigmoid colon are from the sigmoidal artery and vein, branches of the IMA and IMV.
- The splenic flexure of the colon has a watershed blood supply and it is prone to ischemia and anastomotic leaks.
- The splenic flexure is connected to the lower pole of the spleen with the splenocolic ligament. Excessive traction of the splenic flexure of the colon can avulse the splenic capsule and cause troublesome bleeding.

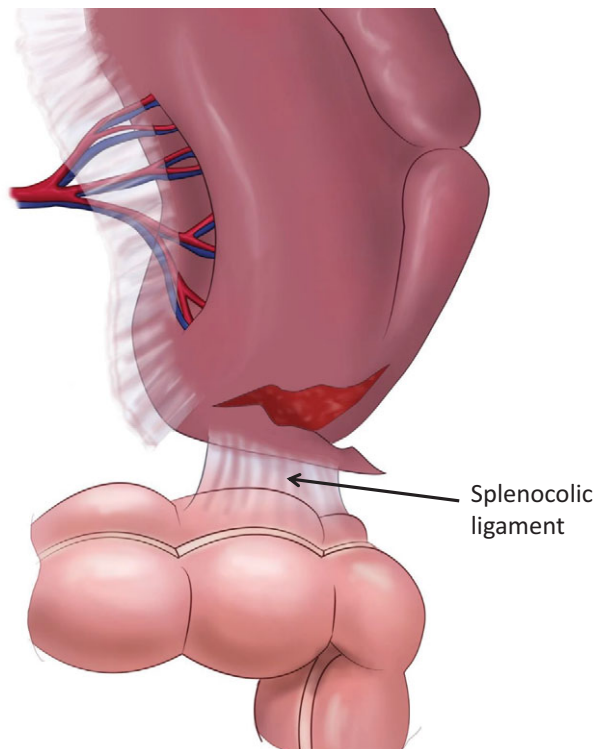


Figure 25.10 Excessive traction on the splenic flexure of the colon may cause avulsion of the splenic capsule and bleeding.

General Principles

- All paracolic hematomas due to penetrating trauma should be explored to exclude underlying injury.
- Control of the hemorrhage takes precedence over intestinal spillage. Fecal spillage and peritoneal contamination can be temporarily controlled with a clamp, whipstitch, or stapling of the perforation.
- Resection is reserved for destructive injuries. In nondestructive injuries, a two-layer primary repair should be performed.
- The selection of a stapled vs. hand-sewn anastomosis is largely a matter of surgeon discretion and has no effect on anastomotic leak.
- A colostomy has no role in patients undergoing primary repair of the colon, irrespective of associated injuries, contamination, blood transfusions, or hemodynamic instability.
- In destructive injuries requiring resection, the existing evidence supports primary anastomosis. Diversion with a colostomy should be considered only in the small group of patients with compromised blood supply or in extraperitoneal rectal injuries in which the repair was incomplete or questionable.
- Due to the high rates of wound infection after colonic injury, the skin should generally be left open at the initial operation and managed with delayed primary closure.

Negative pressure wound therapy is a useful modality to manage the open wound.

Tips and Pitfalls

- The splenic flexure is the most challenging portion of the colon to mobilize. During its mobilization, caution should be exercised to avoid excessive downward traction of the colon, which may cause avulsion of the splenic capsule and troublesome bleeding.
- Perform good debridement of all colon wounds, especially gunshot wounds, before any repair. In destructive injuries, the resection should ensure healthy and well-perfused edges and the anastomosis should be tension-free.
- During mobilization of the right or left colon, the ureters should be identified and protected.

Rectum

Surgical Anatomy

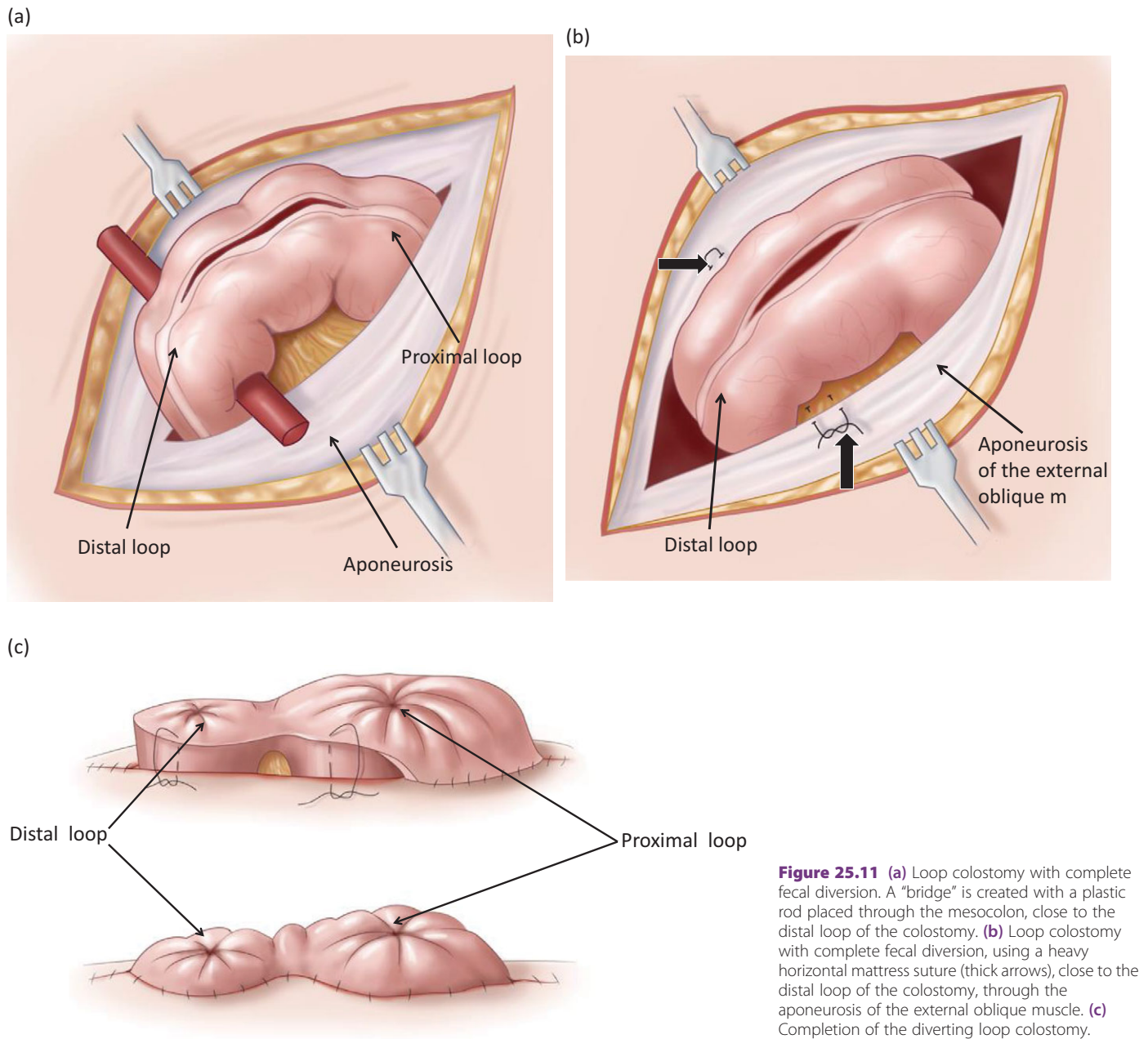
- The rectum is about 15 cm long and only the upper two thirds anteriorly and the upper one third laterally are covered by peritoneum. The lower third is completely extraperitoneal and makes exposure and repair of any injuries difficult.
- The rectum receives its blood supply from the superior rectal artery off the inferior mesenteric artery, the middle rectal artery off the internal iliac artery, and the inferior rectal artery off the internal pudental artery.

General Principles

- Intraperitoneal rectal injuries are managed like colon injuries, the vast majority with primary repair.
- In managing rectal injuries, routine fecal diversion, presacral drainage, and distal rectal washout do not offer any advantages and may be associated with worse outcomes. Fecal diversion should be considered in selected cases with extraperitoneal rectal injuries, where satisfactory repair cannot be performed.
- Low extraperitoneal rectal injuries can be managed with transanal repair, if technically feasible. If the injury is destructive, a defunctioning loop colostomy should be performed.
- A properly constructed loop colostomy may achieve complete fecal diversion and avoid the complex reconstruction required after a Hartmann end-colostomy. The Hartmann's colostomy should be reserved for patients with extensive destruction of the rectum.
- Extraperitoneal injuries, which are difficult to repair because they are too low for transabdominal repair and too high for transanal repair, can be managed with a proximal diverting colostomy alone, without repair of the perforation.

Tips and Pitfalls

- Patients with suspected extraperitoneal rectal injuries should be placed on the operating table in the lithotomy position for rigid sigmoidoscopy evaluation and possible transanal repair of low rectal injuries.
- Low rectal injuries may be repaired transanally and high rectal injuries can be accessed transperitoneally. In mid-rectal injuries, the exposure may be difficult. In these cases, a proximal diverting sigmoid loop colostomy without repair of the rectal perforation should be considered.
- A properly constructed loop colostomy can achieve satisfactory fecal diversion. A “bridge” can be created by placing a plastic rod or a silk 1 horizontal mattress suture through the aponeurosis of the external oblique muscle and through the mesocolon, close to the distal loop of the colostomy. This results in occlusion of the distal opening of the colostomy.
- In the presence of associated genitourinary or vascular injuries, separate the repairs with omentum, in order to reduce the risk of rectovesical fistula or infection of the vascular graft.
- Complex anorectal injuries after open pelvic fractures should be managed with hemostasis, wound packing, and a sigmoid colostomy.



War-Related Colorectal Injuries

- Battlefield injuries have significant differences from civilian injuries. Blast injuries or high-velocity missile injuries are much more destructive than most civilian trauma. Medical evacuation, long transportation times, and lack of continuity of care should be taken into account in deciding the method of operative management of colorectal injuries.
- Simple colon injuries can be managed with debridement and a two-layer anastomosis or repair. A colostomy should be considered in blast injuries or other catastrophic colorectal injuries.

Duodenum

Elizabeth R. Benjamin, Edward Kwon, and Demetrios Demetriades

Surgical Anatomy

- The duodenum lies in front of the right kidney and renal vessels, the right psoas muscle, the inferior vena cava, and the aorta (Figure 26.1).
- The duodenum is approximately 25 cm in length. It is the most fixed part of the small intestine and has no mesentery. It is anatomically divided into four parts:
 - The superior or first portion is intraperitoneal along the anterior half of its circumference. Superiorly, the first portion is attached to the hepatoduodenal ligament. The posterior wall is associated with the gastroduodenal artery, common bile duct, and the portal vein.
 - The descending or second portion shares a medial border with the head of the pancreas. It is bordered posteriorly by the medial surface of the right kidney, the right renal vessels, and the inferior vena cava. The hepatic flexure and transverse colon cross anteriorly. The common bile duct and main pancreatic duct drain into the medial wall of the descending duodenum.
 - The transverse or third portion is also entirely retroperitoneal. Posteriorly, it is bordered by the

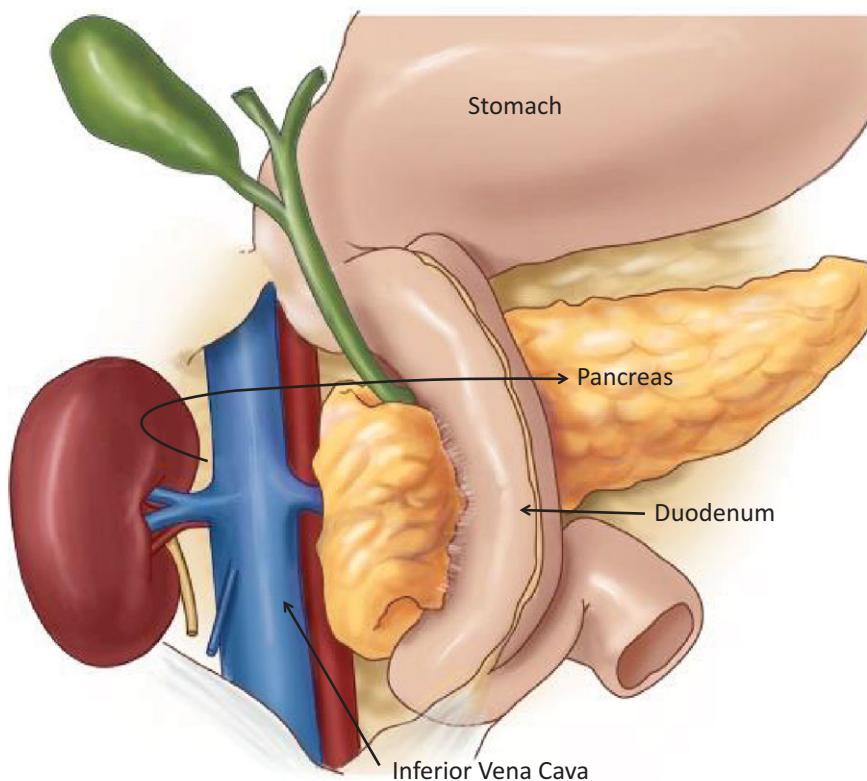


Figure 26.1 The duodenum lies in front of the right kidney and renal vessels, the inferior vena cava, and the aorta. Exposure after medial rotation of the duodenum and head of the pancreas.

inferior vena cava and the aorta. The superior mesenteric vessels cross in front of this portion of the duodenum.

- The ascending or fourth portion of the duodenum is approximately 2.5 cm in length and is primarily retroperitoneal, except for the most distal segment. It crosses anterior to and ascends to the left of the aorta to join the jejunum at the ligament of Treitz.
- The common bile duct courses laterally within the hepatoduodenal ligament and lies posterior to the first portion of the duodenum and pancreatic head, becoming partially invested within the parenchyma of the pancreatic head. The main pancreatic duct then joins the common
- The vascular supply to the duodenum is intimately associated with the head of the pancreas. The head of the pancreas and the second portion of the duodenum derive their blood supply from the anterior and posterior pancreaticoduodenal arcades (Figure 26.2). These arcades lie on the surface of the pancreas near the duodenal C loop. Attempts to separate these two organs at this location usually results in ischemia of the duodenum.

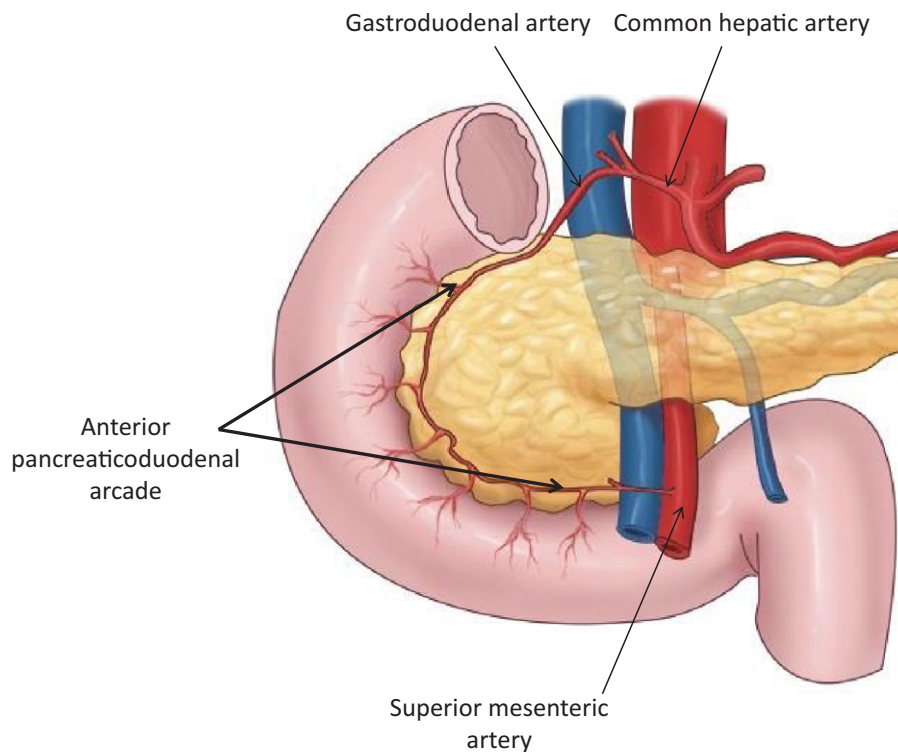


Figure 26.2 The head of the pancreas and the second portion of the duodenum derive their blood supply from the anterior and posterior pancreaticoduodenal arcades. Attempts to separate the two organs at this location usually result in ischemia of the duodenum.

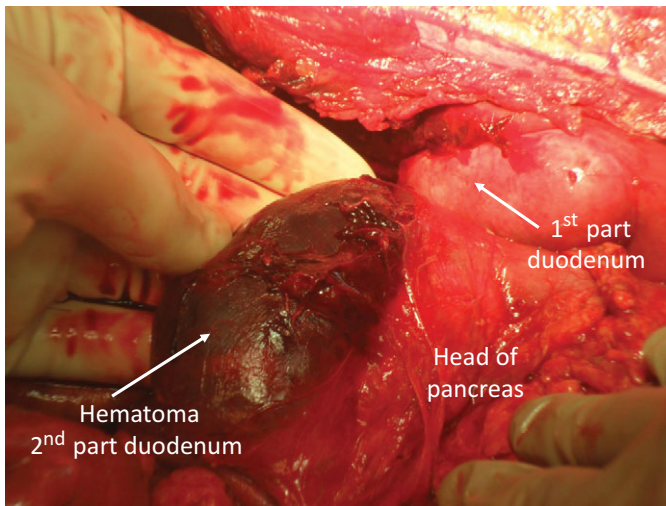


Figure 26.3 Hematoma of the second part of the duodenum due to blunt trauma. All duodenal hematomas secondary to blunt or penetrating trauma found during laparotomy should be explored to rule out underlying perforation.

General Surgical Principles

- All periduodenal hematomas secondary to blunt or penetrating trauma found during laparotomy should be explored to rule out underlying perforation (Figure 26.3). However, blunt traumatic hematomas diagnosed by CT scan may be observed if there are no other injuries.
- The majority of duodenal lacerations can be managed with debridement and transverse duodenorrhaphy.
- Resection and primary anastomosis of the second portion of the duodenum is tenuous due to the high risk of vascular compromise during mobilization and proximity to the ampulla of Vater.
- Injuries involving the medial aspect of the second portion of the duodenum may be more effectively explored from within the lumen via a lateral duodenotomy. Avoid dissection of the duodenum from the head of the pancreas due to the high risk of devascularization and duodenal necrosis.
- Routine pyloric exclusion should not be performed. Exclusion should be reserved for severe injuries requiring a complex repair or a repair with tenuous blood supply.
- In complex pancreaticoduodenal injuries, consider damage control techniques and delayed reconstruction.
- Wide local drainage of duodenal repairs with closed suction drains should be performed. The drains should not directly overlie the repair.
- Distal feeding access, through a feeding jejunostomy, should be considered in patients with complex duodenal injuries.

- Although rare, severe destructive injuries to the duodenum that include the pancreatic head may require a pancreaticoduodenal resection. These cases should be considered for damage control, with a staged resection followed by delayed reconstruction.

Special Surgical Instruments

- Complete trauma laparotomy tray, Bookwalter self-retaining abdominal retractor, surgical headlamp.

Positioning

- Standard supine positioning with arms abducted to 90°.
- Standard trauma preparation from the nipples to the mid thighs.

Incision

- A standard midline laparotomy incision from the xiphoid process to the pubic symphysis.

Operative Technique

Exposure

- A self-retaining abdominal retractor is useful to retract the abdominal wall and the liver cephalad to expose the duodenal-pyloric junction.
- The anterior surface of the first portion of the duodenum is readily visible.
- The right colon is mobilized to expose the anterior surface of the second and third portions of the duodenum (Figure 26.4).

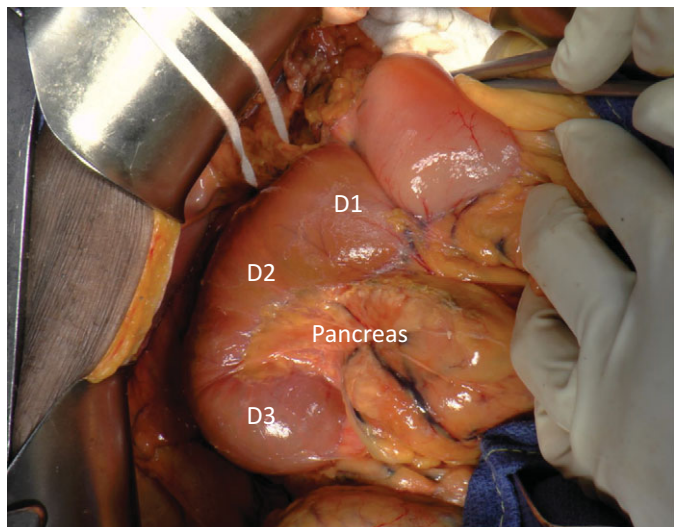


Figure 26.4 The anterior portion of the first part of the duodenum is intraperitoneal and easily visible. After mobilization of the right colon hepatic flexure, the anterior surface of the second and third parts of the duodenum and the head of the pancreas come into view.

- A Kocher maneuver is performed by incising the lateral peritoneal attachments of the first, second, and proximal third portions of the duodenum to the superior mesenteric vein (SMV), exposing their lateral aspects.
 - The C-loop of the duodenum and the pancreatic head are retracted medially to expose their posterior surfaces. Avoid excessive superior traction to prevent superior mesenteric vein injury.
 - Gerota's fascia of the right kidney and the inferior vena cava are visible posteriorly (Figure 26.5).
- To increase exposure to the remainder of the third and fourth portions of the duodenum and retroperitoneal vessels, a right medial visceral rotation or Cattell-Braasch maneuver is performed (Figure 26.6).
 - Incise the lateral peritoneal attachments of right colon from the hepatic flexure to the cecum and retract the colon medially.
 - When medializing the right colon, the anterior surface of the second and third portion of the duodenum will be exposed.

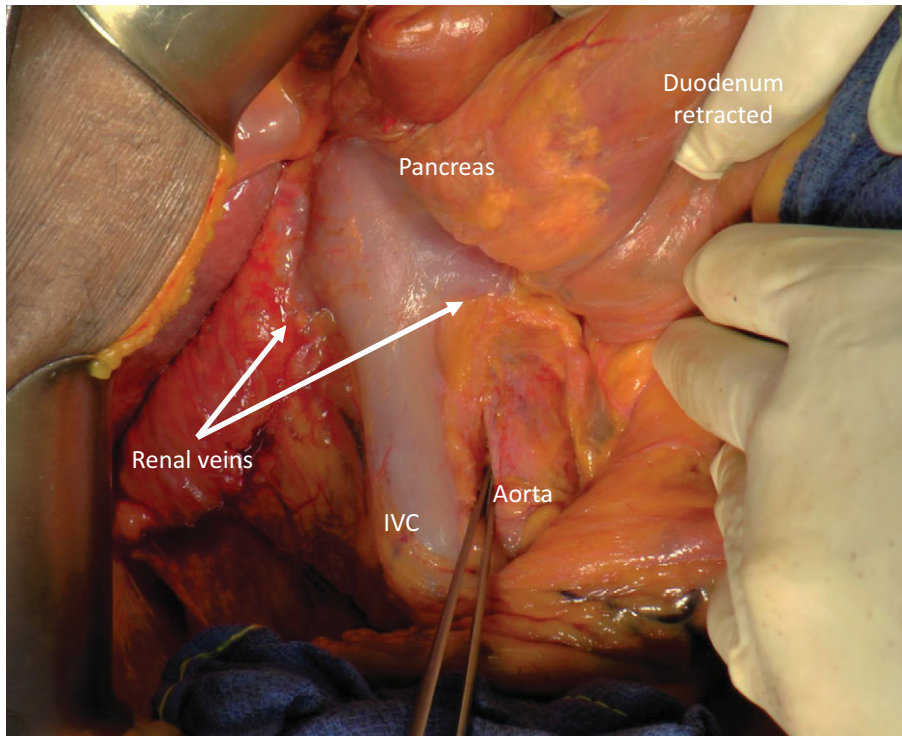


Figure 26.5 In performing a Kocher maneuver, the duodenum is mobilized medially until the IVC and left renal vein are exposed.

- Continue the inferior margin of the lateral peritoneal incision onto the visceral peritoneum, posterior to the small bowel mesentery, in an oblique fashion from the ileocecal junction towards the ligament of Treitz. The right colon and small bowel are retracted cephalad and to the left.
- The superior mesenteric vessels are retracted with the small bowel, towards the patient's head and left side, and are no longer crossing the duodenum. The third and proximal fourth portions of the duodenum are now accessible ([Figure 26.7](#)).

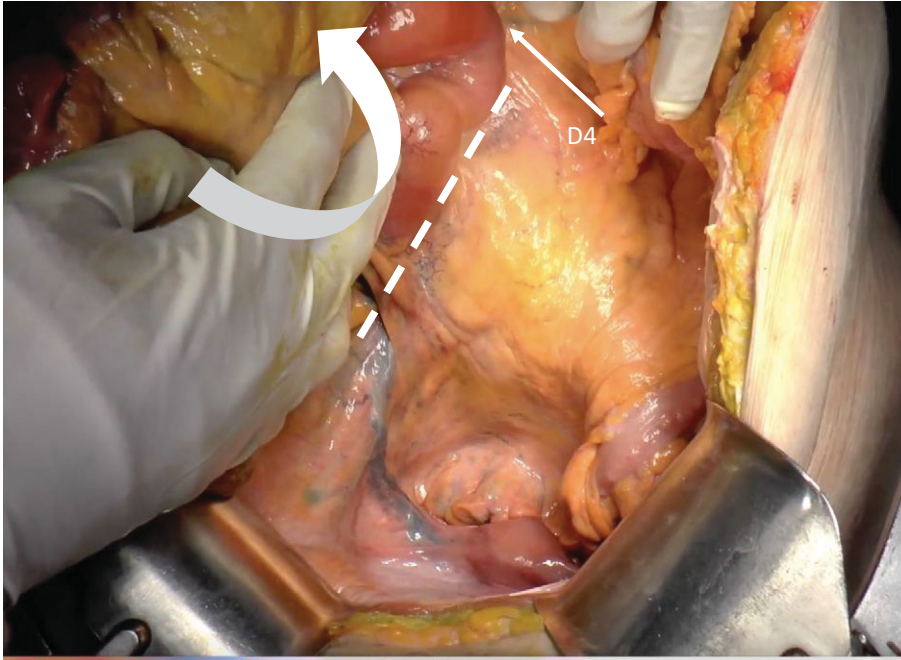


Figure 26.6 In performing a Cattell-Braasch maneuver, the right colon is mobilized and the bowel is retracted to the right. An incision is made along the retroperitoneum below the small bowel mesentery in an oblique fashion from the ileocecal junction toward the ligament of Treitz. This will allow full superior retraction of the viscera exposing the fourth portion of the duodenum

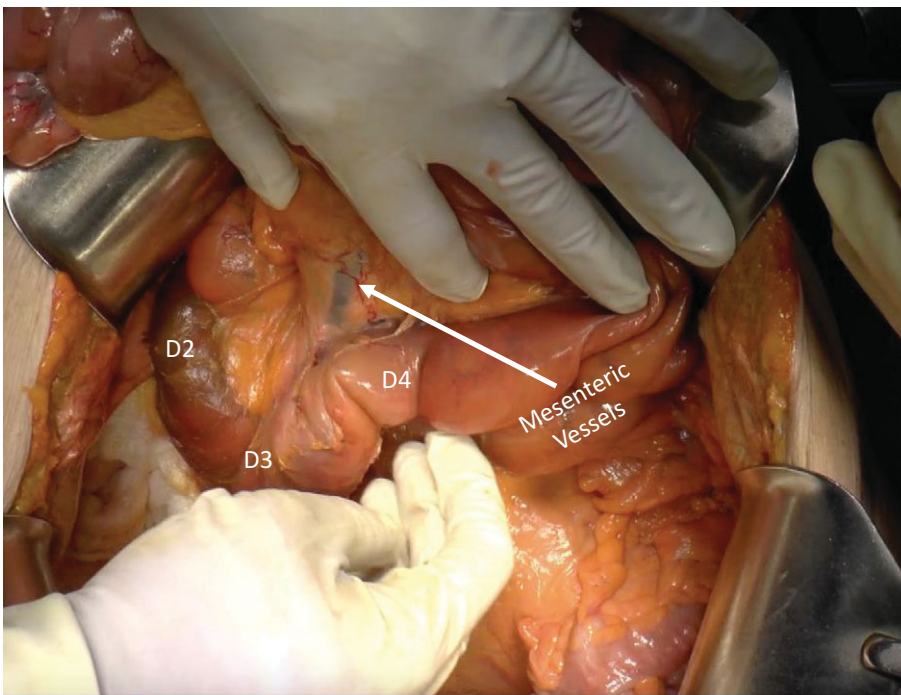


Figure 26.7 Complete exposure of the entire duodenum with the viscera retracted superiorly and to the left.

- The distal fourth portion of the duodenum can be exposed by incising the ligament of Treitz (**Figure 26.8 a,b**).
 - The transverse colon is retracted superiorly and the small bowel is gently retracted inferiorly and to the patient's right. The ligament of Treitz is identified at the root of the mesentery where the fourth portion of the duodenum emerges from under the mesenteric vessels.
 - The root of the mesentery should be palpated to identify the location of the superior mesenteric vessels to the right of the ligament of Treitz to prevent injury prior to division.

(a)

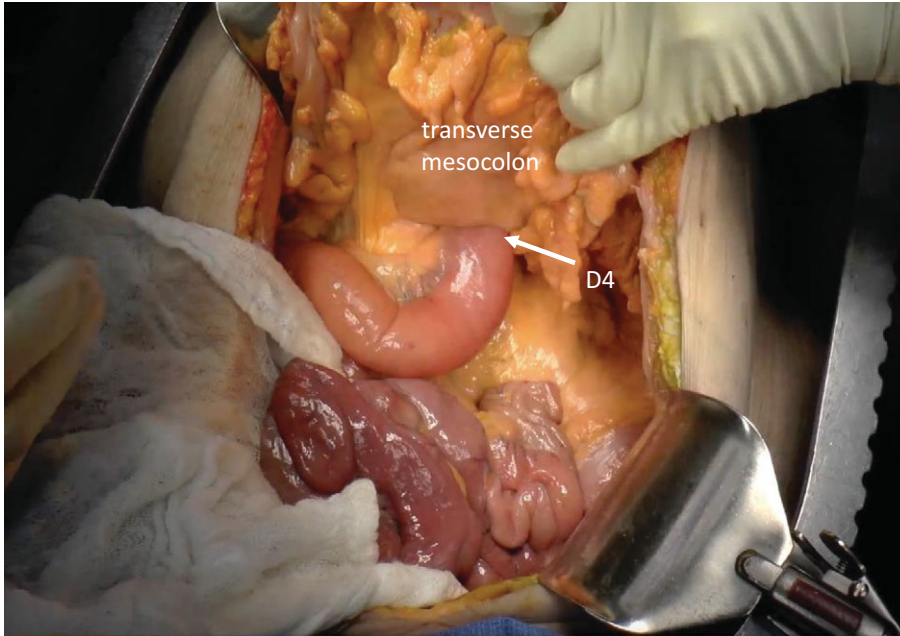
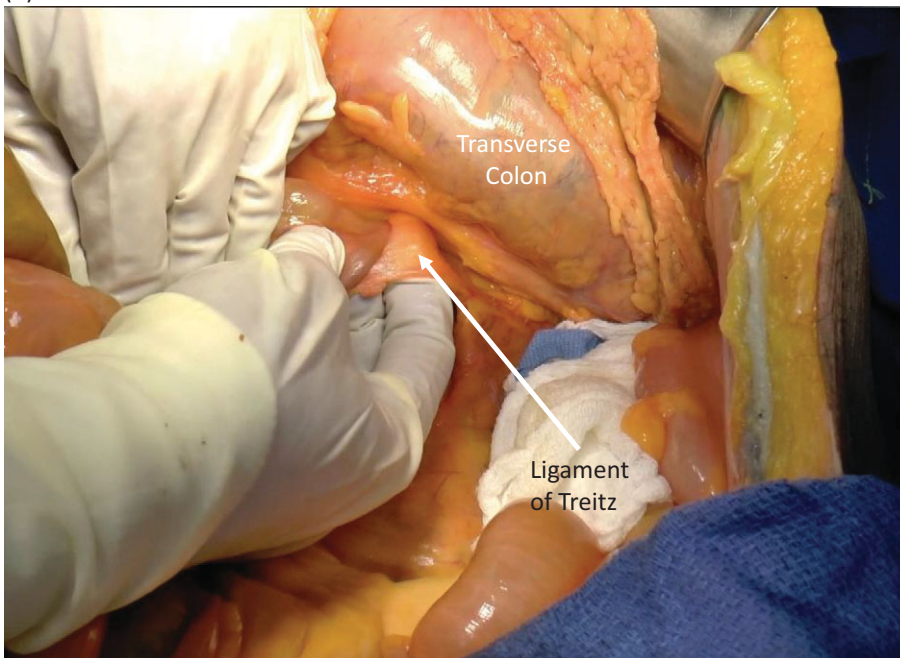


Figure 26.8 Exposure of the distal portion of the fourth part of the duodenum can also be achieved by releasing the ligament of Treitz as it attaches to the base of the transverse mesocolon. The transverse mesocolon is retracted superiorly (**a**) and the division of the ligament of Treitz exposes and mobilizes the duodenal-jejunal junction (**b**).

(b)



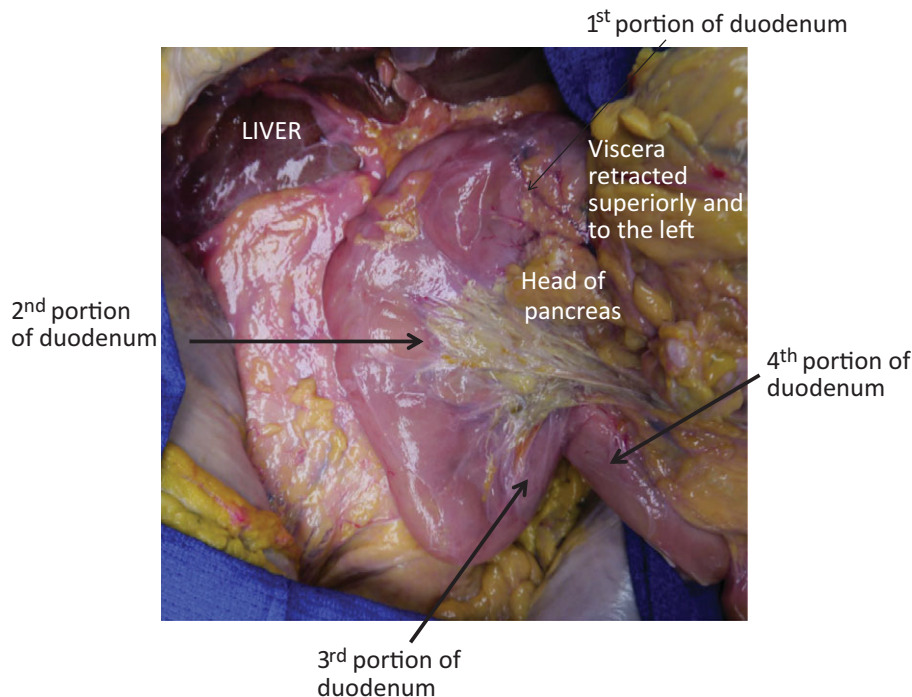


Figure 26.9 Complete exposure of all parts of the duodenum after the Cattell-Braasch maneuver. The viscera is retracted superiorly and to the left. The superior mesenteric vessels are no longer crossing the duodenum.

- After completion of the full Kocher and Cattell-Braasch maneuvers, the entire duodenum is mobile and exposed for injury repair (Figure 26.9).

Repair

- All duodenal hematomas identified intraoperatively must be explored to rule out underlying perforation. A seromuscular incision is made overlying the hematoma and the hematoma is evacuated. The duodenum should be carefully examined for full thickness injury at the site of the hematoma.
- Most duodenal lacerations can be debrided and repaired primarily. Repairs should be performed transversely in two layers using a full thickness continuous 3-0 absorbable suture as the inner layer, and 3-0 seromuscular Lembert sutures as the outer layer, taking care not to narrow the duodenal lumen at the site of repair.
 - If adequate mobilization is not possible for transverse closure, the injury may be repaired in a longitudinal fashion, if this can be accomplished without significant luminal narrowing. If there is significant stenosis, a gastrojejunostomy should be performed, in addition to the repair.
 - Repairs may be buttressed using adjacent omentum.
 - Some injuries may not be amenable to primary repair and may require more complex repairs such as jejunal mucosal or serosal patch.
- Transections and injuries involving >50% of the circumference of the first, third, and fourth portions of the duodenum may require segmental resection and duodenoduodenostomy or duodenojejunostomy.
 - The injured segment is resected and a two-layer end-to-end hand-sewn anastomosis is created, using a full thickness continuous 3-0 absorbable suture and seromuscular 3-0 Lembert sutures.
 - If a tension-free anastomosis is unable to be created, a Roux-en-Y duodenojejunostomy may be required.
- Segmental resection of the second portion is limited by the ampulla of Vater and the common blood supply, with the pancreas making it particularly susceptible to vascular compromise during mobilization.
- Pyloric exclusion should be used selectively for injuries involving the second portion of the duodenum, combined pancreatic and duodenal injuries, and otherwise tenuous repairs (Figure 26.10 a-c).
 - An anterior gastrotomy is created along the greater curvature of the stomach, near the pylorus.
 - The pylorus is identified and grasped via the gastrotomy with a Babcock clamp and a purse-string suture using a size 0 absorbable suture.
 - An alternative technique involves stapling of the post-pyloric duodenum with a TA 55 4.8 mm stapling device (Figure 26.11).
 - The pyloric exclusion is completed with a gastrojejunostomy, utilizing the previous gastrotomy.

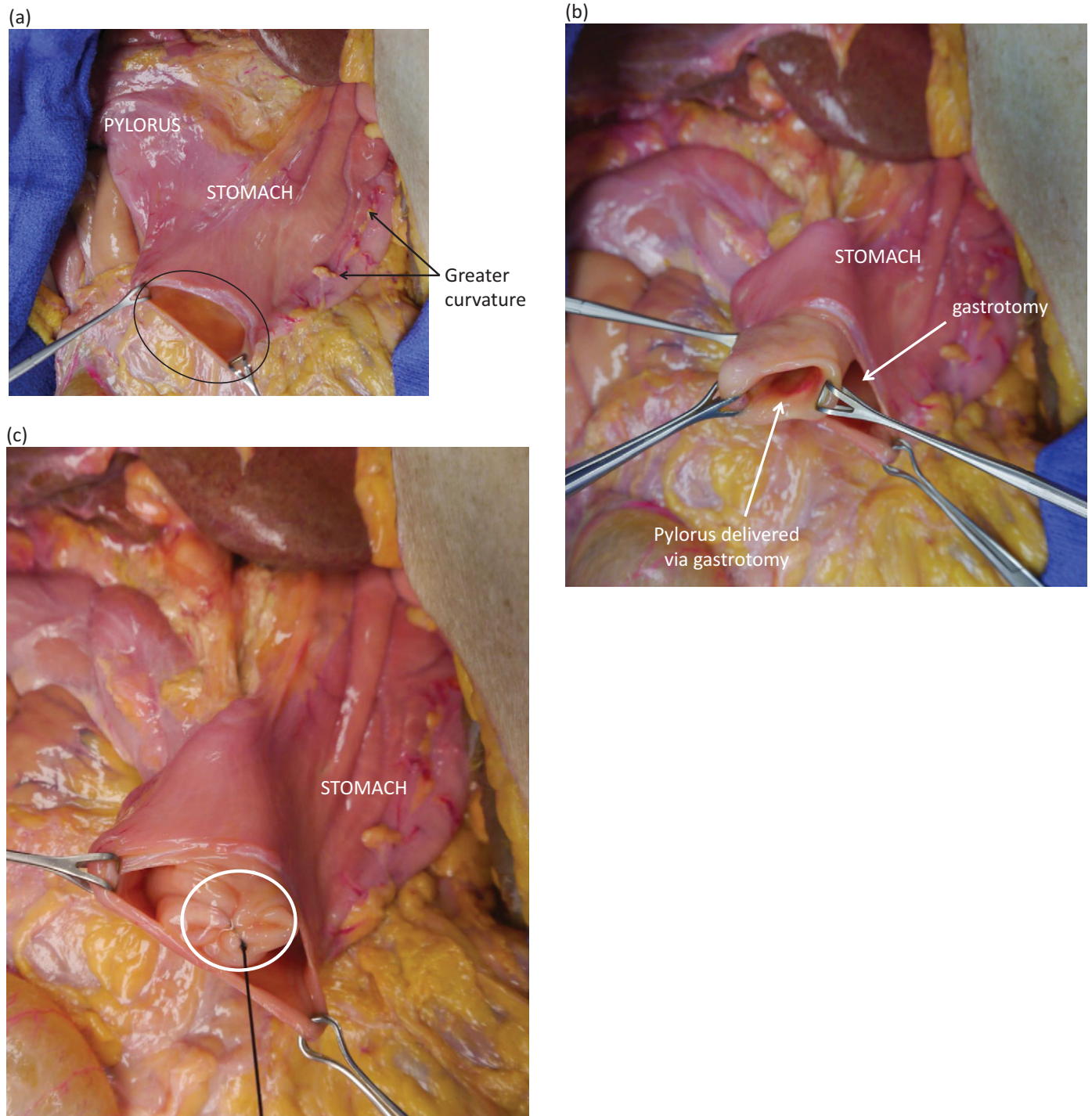


Figure 26.10 Pyloric exclusion: a gastrotomy (circle) is created along the greater curvature of the stomach which will also be used to create a gastrojejunostomy **(a)**. The pylorus is then grasped with a Babcock clamp and delivered through the gastrotomy **(b)**. An 0 absorbable suture is utilized to close the pylorus (circle) and a gastrojejunostomy is created **(c)**.

- Destructive injuries to the pancreatic head and duodenum may require pancreaticoduodenectomy (Whipple procedure).

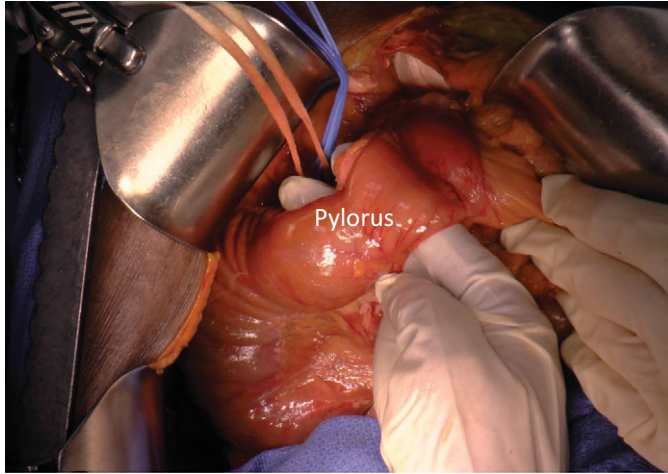


Figure 26.11 Stapled pyloric exclusion: A window on the posterior surface of the pylorus is dissected to allow passage of a TA stapler across the pylorus.

- These patients are often hemodynamically unstable and these injuries are best managed with completion of the resection and delayed reconstruction as a second planned operation.
- Associated sources of hemorrhage should be considered and include from superficial to deep: (1) duodenum and pancreas, (2) superior mesenteric vessels and portal vein, (3) inferior vena cava, renal vessels, and aorta.
- Damage control techniques for duodenal injuries include resection without anastomosis or wide drainage and exteriorization of the injury, with lateral duodenostomy and planned delayed reconstruction.

Tips and Pitfalls

- The superior mesenteric vein and its branches are easily injured with excessive traction during the Kocher and Cattell-Braasch maneuvers.
- Care should be taken during repair and anastomosis involving the second portion of the duodenum to identify and preserve the ampulla of Vater.
- Separation of the second portion of the duodenum from the head of the pancreas results in ischemia and necrosis of the duodenum.
- During division of the ligament of Treitz, proceed carefully to avoid injury to the superior mesenteric artery on the right and the inferior mesenteric vein on the left.
- Injuries of the medial aspect of the second portion of the duodenum can be explored from within the lumen, through a lateral duodenotomy.
- In complex injuries including the pancreaticoduodenal complex, damage control with delayed reconstruction should be considered. Once stabilized, reconstruction should proceed at the earliest possible time to avoid bowel edema and suppurification.
- In complex injuries, distal feeding access should be considered through a nasojejunal or jejunostomy tube.
- Closed suction drains should be placed around but not directly overlying duodenal repairs.

Liver and Biliary Tract Injuries

Kenji Inaba, Zachary D. Warriner, and Kelly Vogt

Surgical Anatomy

- The liver is tethered by the following ligaments:
 - The falciform ligament attaches the liver anteriorly to the diaphragm and the anterior abdominal wall above the umbilicus.
 - The coronary ligaments extend laterally to attach the liver to the diaphragm. Beginning at the suprahepatic inferior vena cava (IVC), the lateral extensions of the coronary ligaments form the triangular ligaments (right and left), which are also attached to the diaphragm.
- The anatomical division of the liver into the eight classic Couinaud segments has no practical application in traumatic liver resection, where the resection planes are nonanatomical and are dictated by the extent of injury. However, the external anatomical landmarks may be useful in planning operative maneuvers.
 - The plane between the center of the gallbladder and IVC runs along the middle hepatic vein, and serves as the line of division between the right and left lobes.
 - The left lobe is divided by the falciform ligament into the medial and lateral segments.
 - Dissection along the falciform ligament should be performed carefully, so as to avoid injury to the portal venous supply to the medial segment of the left lobe inferiorly and the hepatic veins superiorly.

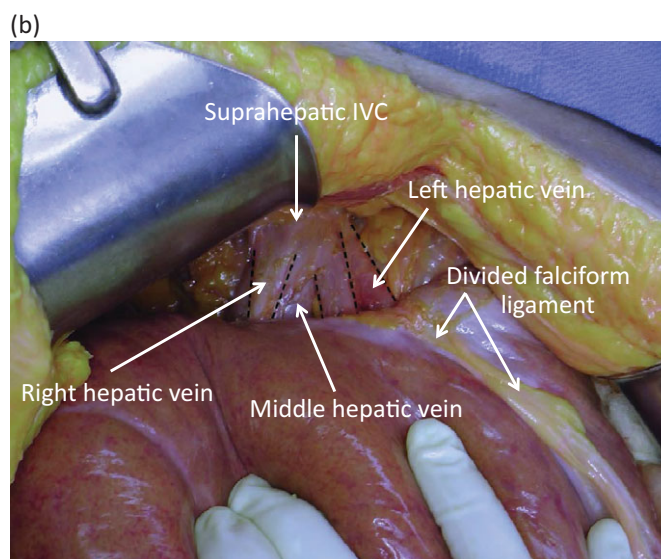
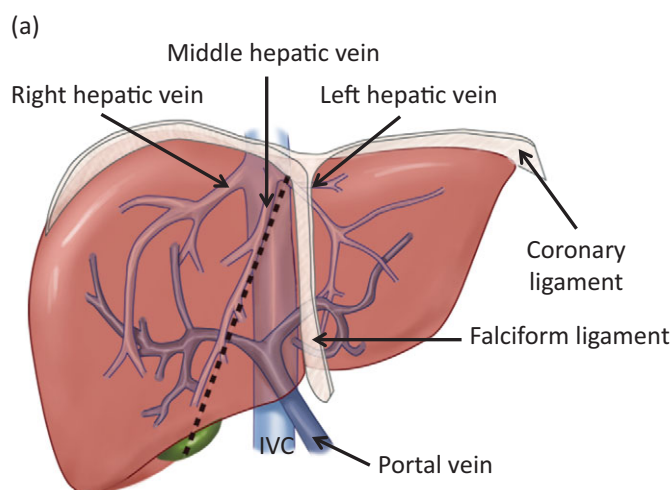


Figure 27.1 (a) Surgical anatomy of the liver. The plane between the gallbladder and inferior vena cava (IVC) (interrupted line) runs along the middle hepatic vein. Dissection along the falciform ligament should be done carefully, so as to avoid injury to the portal venous supply to the medial segment of the left lobe inferiorly and the hepatic veins superiorly. (b) The extrahepatic portions of the three major hepatic veins are visible after division of the falciform and right coronary ligaments, providing venous drainage into the suprahepatic IVC.

- The retrohepatic IVC is approximately 8–10 cm long and is partially embedded into the liver parenchyma. In some cases, the IVC is completely encircled by the liver, further complicating exposure and repair.
- There are three major hepatic veins (right, middle, and left), as well as multiple accessory veins. The first 1–2 cm of the major hepatic veins are extra-hepatic, with the remaining 8–10 cm intra-hepatic. In approximately 70% of patients, the middle hepatic vein joins the left hepatic vein before entering the IVC.
- The common hepatic artery originates from the celiac artery. It is responsible for approximately 30% of the hepatic blood flow, but supplies 50% of the hepatic oxygenation. It branches into the left and right hepatic arteries at the liver hilum in the majority of patients. In a common anatomical variant, the right hepatic artery may arise from the superior mesenteric artery. Less frequently, the entire arterial supply may arise from the superior mesenteric artery. Alternatively, the left hepatic artery may arise from the left gastric artery in 15–20% of patients.
- The portal vein provides approximately 70% of hepatic blood flow, and 50% of the hepatic oxygenation. It is formed by the confluence of the superior mesenteric vein and the splenic vein behind the head of the pancreas. The portal vein divides into right and left extrahepatic branches at the level of the liver parenchyma.
- The porta hepatis contains the hepatic artery (medial), common bile duct (lateral), and portal vein (posterior, between the common bile duct and the hepatic artery).
- The right hepatic duct is easier to expose after removal of the gallbladder.
- The left hepatic duct, the left hepatic artery, and the left portal vein branch enter the undersurface of the liver near the falciform ligament.

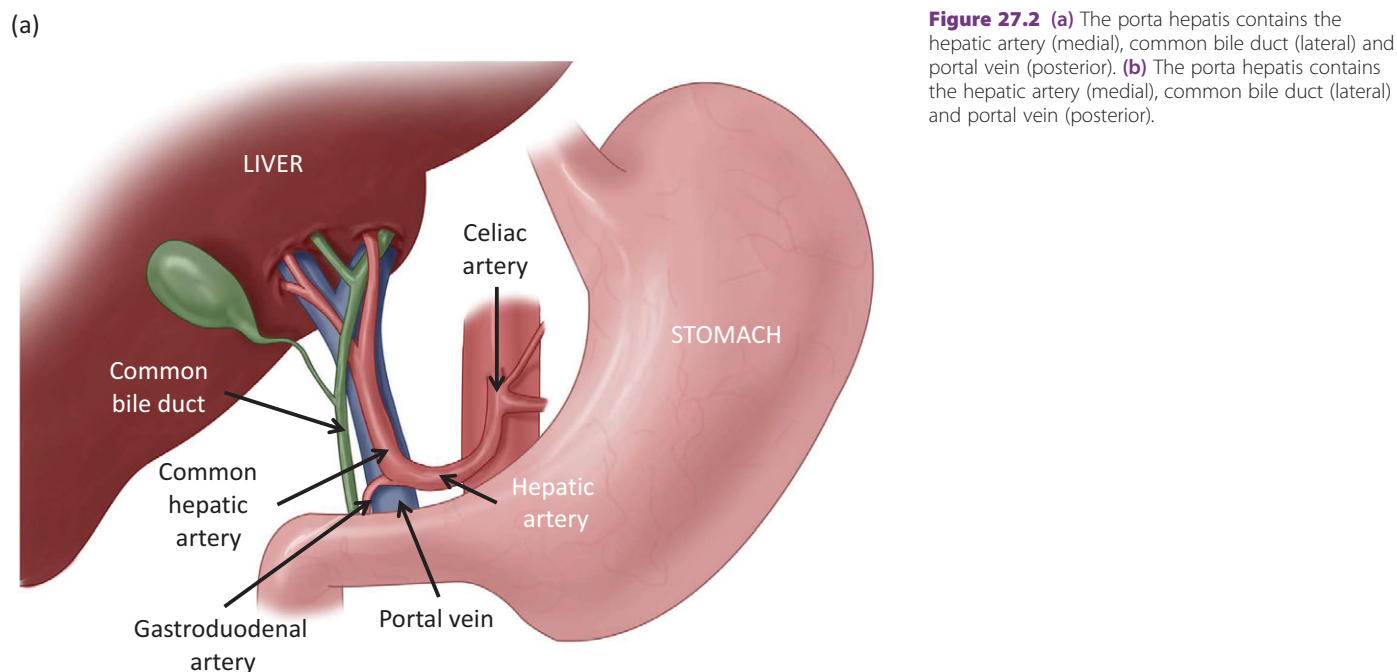


Figure 27.2 (a) The porta hepatis contains the hepatic artery (medial), common bile duct (lateral) and portal vein (posterior). (b) The porta hepatis contains the hepatic artery (medial), common bile duct (lateral) and portal vein (posterior).

(b)

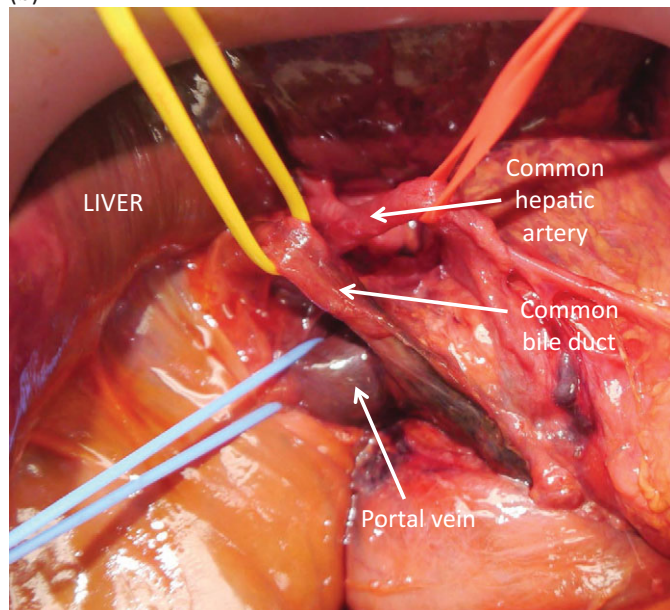


Figure 27.2 (cont.)

General Principles

- The liver is the most commonly injured intra-abdominal solid organ.
- Most injuries to the liver do not require operative intervention.
- Angioembolization is an effective adjunct to the nonoperative management of high-grade liver injuries, especially in patients with evidence of active extravasation on contrast-enhanced CT scan. After damage control packing of complex liver injuries operatively, angioembolization may be an effective adjunct.
- Damage control procedures have revolutionized the management of complex liver injuries and, in the appropriate cases, it should be considered early. Packing is the mainstay of damage control for the liver.
- A contained stable retrohepatic hematoma should not be opened. If the hematoma is expanding or leaking, and it is possible to control with packing alone, this technique should be the operative treatment of choice. The operation should then be terminated and the patient brought to the ICU for ongoing resuscitation. Angioembolization may be of use, especially if there is associated parenchymal damage

that was packed. The patient can return to the operating room for pack removal after complete physiological stabilization.

- Adequate mobilization of the liver, by division of the falciform and coronary ligaments, is essential in the management of posterolateral injuries.
- Retrohepatic IVC or hepatic vein injury should be suspected if bleeding from the posterior liver worsens during anterior retraction of the liver.
- In approximately 80–85% of patients undergoing operation, the liver injury can be managed by relatively simple surgical techniques, such as application of local hemostatic agents, electro-coagulation, superficial suturing, or drainage. The remaining 15–20% of cases require more complex surgical techniques.

Special Surgical Instruments

- A hybrid operating room suite with angioembolization capability is highly desirable.
- A standard trauma laparotomy tray, which includes vascular instruments, should be prepared. A sternotomy set should be available in case a median sternotomy is needed for improved exposure of the retrohepatic IVC.
- A fixed self-retaining abdominal retractor, such as an Omni-flex, Bookwalter, or Gomez.
- An electrothermal bipolar vessel sealing system (LigaSure device) is desirable.
- A surgical headlight allows improved visualization of right-sided and posterior injuries.

Positioning

- Supine position, with upper extremities abducted to 90°.
- Skin antiseptic preparation should include the chest, abdomen, and groin.
- Use upper and lower body warming devices.

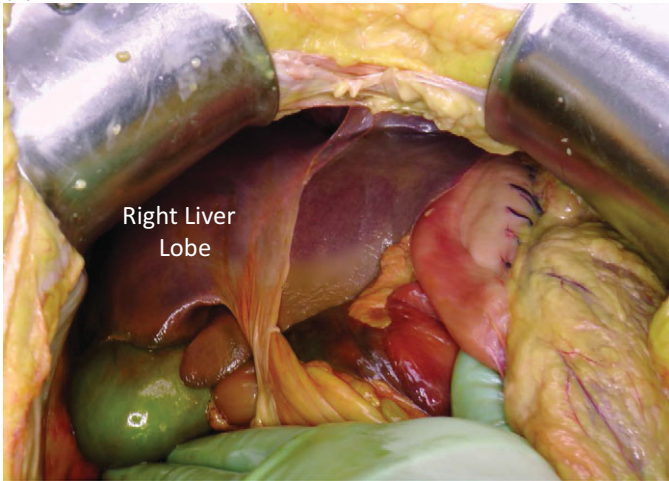
Incisions

- The initial incision should be a midline laparotomy. This incision provides limited exposure to the posterior and lateral parts of the liver. Depending on the anatomical area and the extent of the liver injury, additional incisions may be required.
- To obtain better access to posterolateral liver injuries, a right subcostal incision may be required to “T-off” the initial laparotomy.

(a)



(b)



(c)

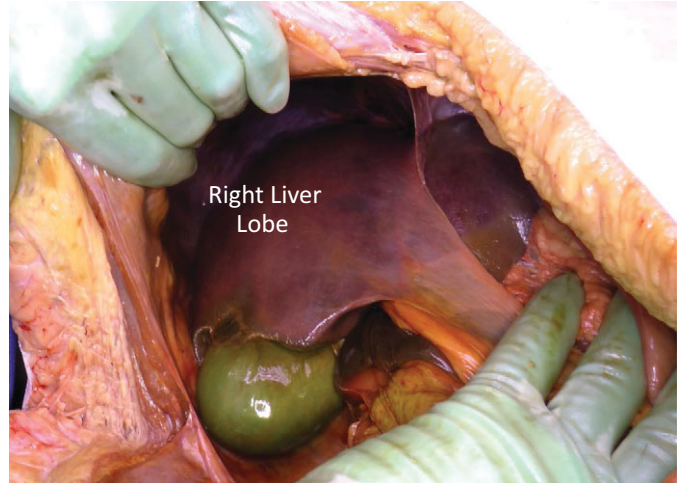
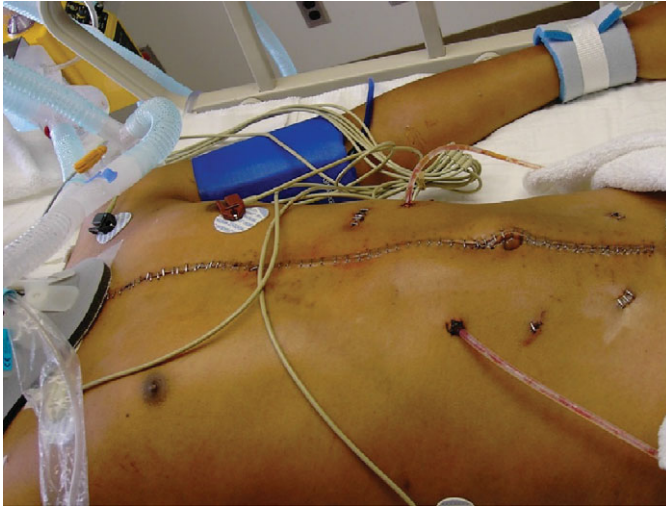


Figure 27.3 (a) Addition of a right subcostal incision to the standard midline laparotomy incision for improved exposure of the liver. (b) Poor exposure of the liver through a midline laparotomy. (c) Improved exposure of the liver with the addition of a right subcostal incision.

- A median sternotomy may be required to obtain access to the intrapericardial segment of the suprahepatic IVC for vascular occlusion of the liver, or to the heart for placement of an atriocaval shunt.

(a)



(b)

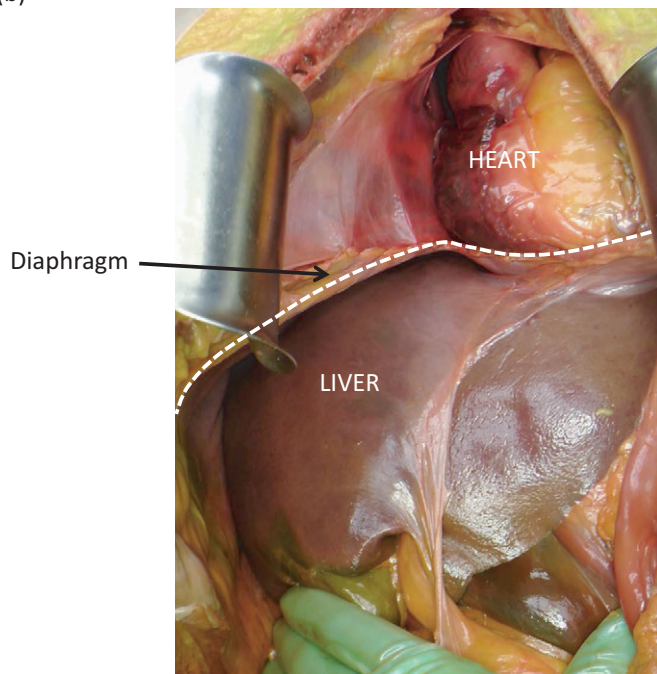


Figure 27.4 A median sternotomy may be added to the midline laparotomy in cases requiring access to the intrapericardial segment of the inferior vena cava for vascular occlusion of the liver, or to the heart for placement of an atriocaval shunt.

- If the patient has undergone a right thoracotomy, access to the posterior liver and retrohepatic venous structures can best be obtained by joining the laparotomy to the thoracotomy. The diaphragm is then divided, taking care to leave a cuff of diaphragm for reconstruction.
- If the patient has a severe liver injury best handled by damage control packing, this should be recognized early and the abdominal wall and ligaments left intact to allow for more effective packing.

Operative Techniques

- The first step after entering the peritoneal cavity is to assess the extent of the liver injury, and examine for other associated injuries.
- Temporary control of liver bleeding may be achieved by finger compression of the liver wound. If this is not effective, cross-clamping of the porta hepatis structures with a vascular clamp through the foramen of Winslow (Pringle maneuver) decreases the vascular inflow to the liver and reduces bleeding.
 - Insert the index finger of the left hand into the foramen of Winslow and then pinch down with your thumb. This can later be replaced with a noncrushing vascular clamp or a Rummel tourniquet.
 - The duration of time for which the Pringle maneuver may be safely used is unknown, but occlusion up to 30 minutes rarely causes any problems.
 - It is important to recognize that failure to control hemorrhage with the Pringle maneuver suggests either aberrant anatomy, or bleeding from the hepatic veins and/or retrohepatic vena cava.

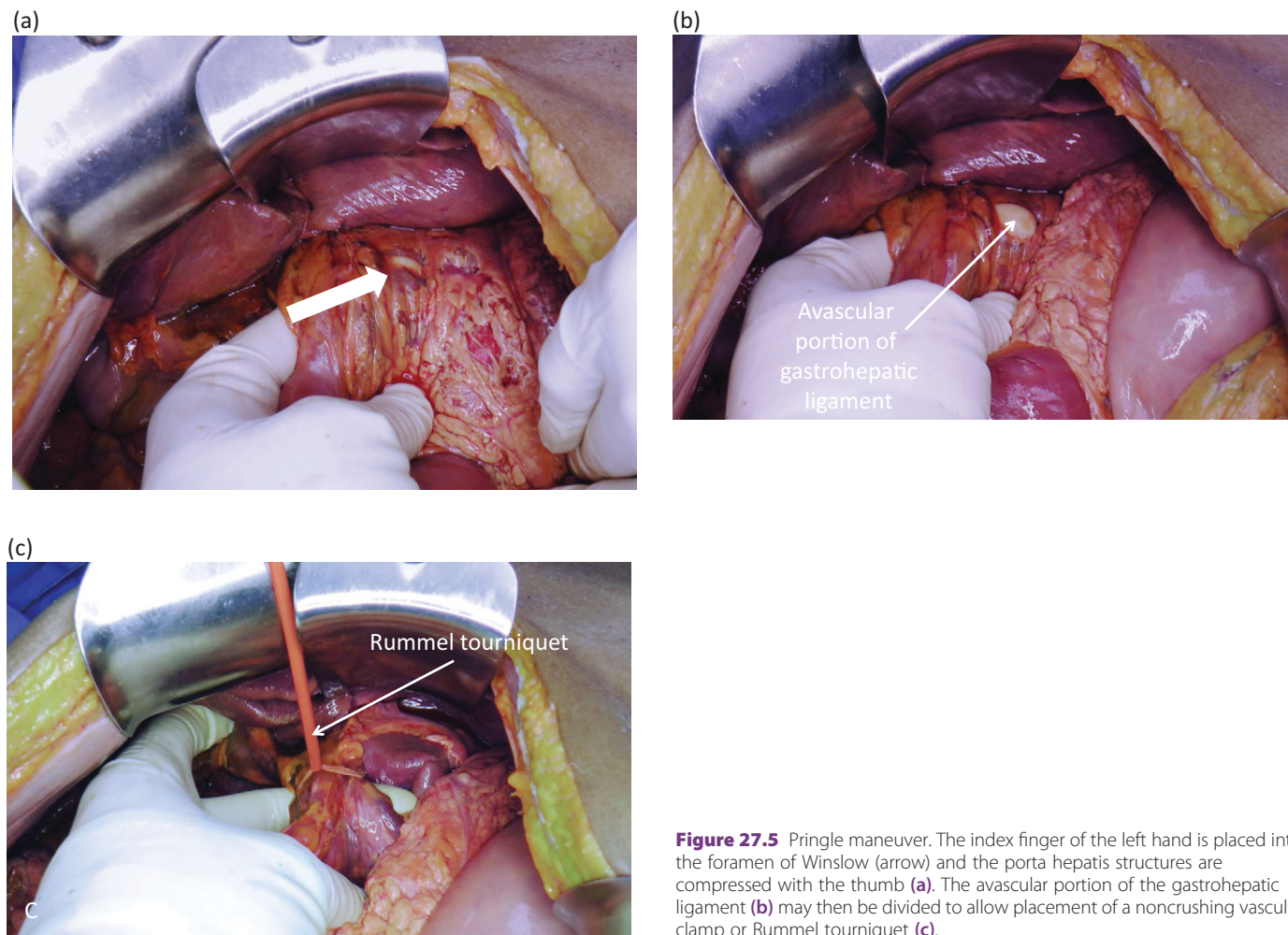


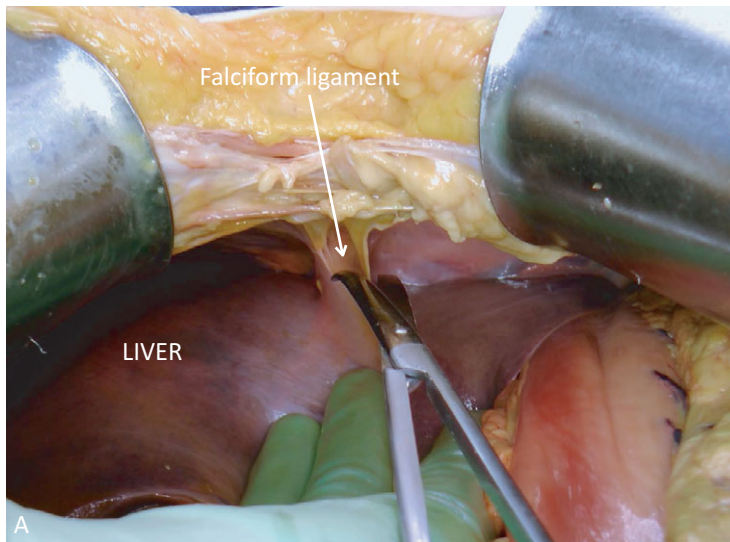
Figure 27.5 Pringle maneuver. The index finger of the left hand is placed into the foramen of Winslow (arrow) and the porta hepatis structures are compressed with the thumb (a). The avascular portion of the gastrohepatic ligament (b) may then be divided to allow placement of a noncrushing vascular clamp or Rummel tourniquet (c).

- Adequate exposure of the liver is critical in the management of severe injuries. The first step is to place three to four laparotomy pads behind the liver, under the diaphragm, and retract the liver anteriorly and inferiorly.
- If this maneuver does not provide adequate exposure, the next step is mobilization of the liver by taking down the falciform and coronary ligaments. During division of the falciform ligament, care should be taken to avoid injury to

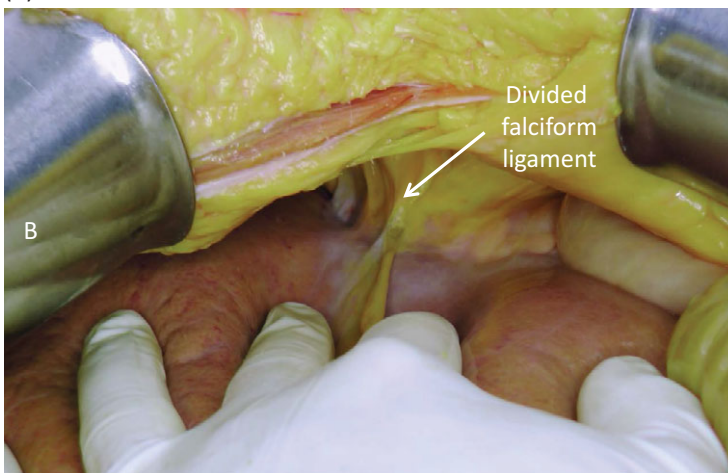
the hepatic veins as the dissection progresses posteriorly. To facilitate this in a rapid fashion, place gentle pressure down on the liver with the falciform between two of your fingers and sharply divide the avascular ligament.

- Bleeding from deep liver lacerations can often be controlled by direct suture-ligation or clipping of any major bleeders, followed by deep, figure-of-eight, tension-free sutures, using 0-chromic on a large blunt-tip liver needle.

(a)



(b)



(c)

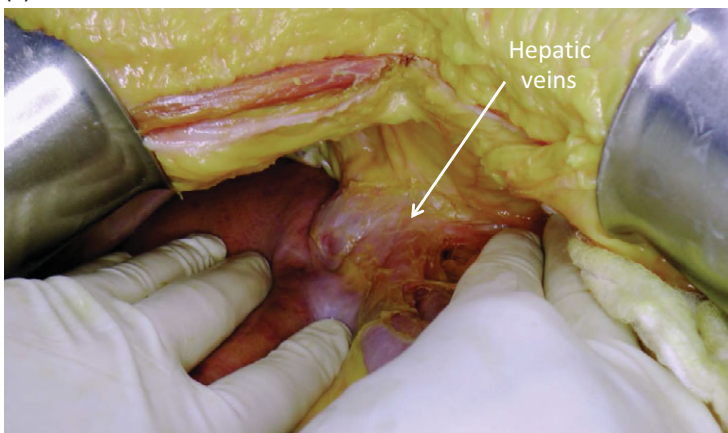


Figure 27.6 Division of the falciform ligament. Place gentle pressure down on the liver with the falciform ligament between two of your fingers, followed by sharp division of the avascular ligament **(a)**. Care should be taken to avoid injury to the hepatic veins as the dissection progresses posteriorly **(b)** as division nears the confluence of the hepatic veins and inferior vena cava **(c)**.

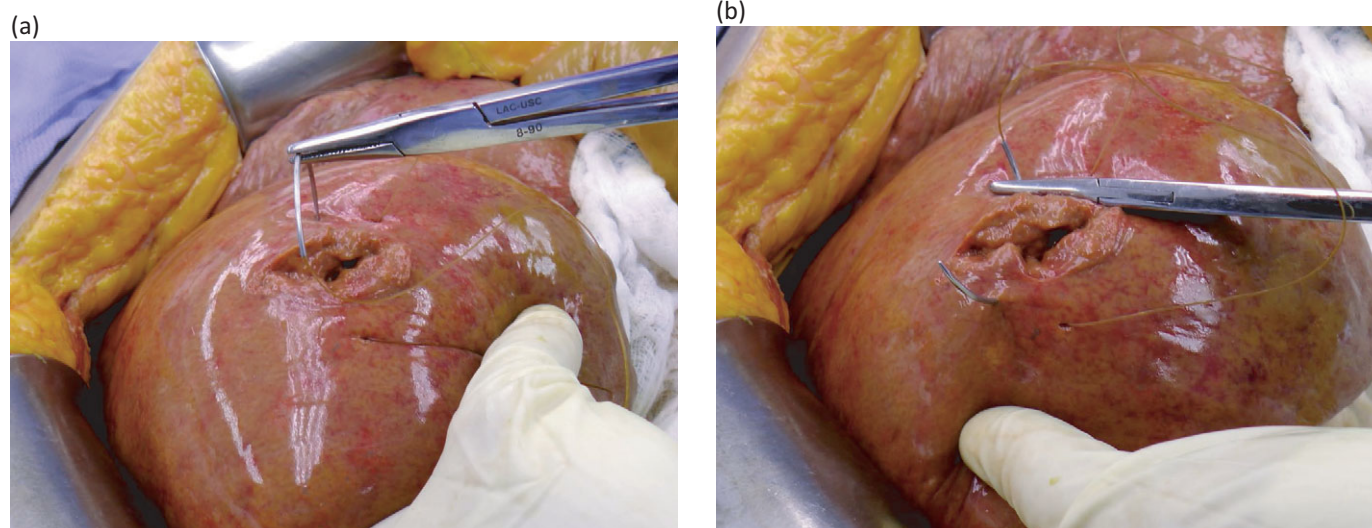


Figure 27.7 Bleeding control of a deep liver laceration with figure-of-eight tension-free 0-chromic sutures on a large blunt tip needle. The needle should enter the liver parenchyma at a 90° angle to avoid tearing of the parenchyma when the suture is tied for tissue approximation.

- Concerns regarding intrahepatic abscess or hemobilia, resulting from the placement of deep sutures have been overstated. These complications can be diagnosed by CT and managed by percutaneous drainage or angiographic embolization.
- Omental packing of large liver wounds may be useful for filling in defects or buttressing a repair.
- Severe bleeding from deep bullet or knife tracts in the liver can be controlled with tractotomy and direct bleeding control or with the use of balloon tamponade.
- Packing of the tract with hemostatic agents or gauze is usually not effective in controlling significant bleeding and it usually results in a large intrahepatic hematoma.
- Tractotomy may be performed along the tract using sequential firings of a linear stapler, finger fracture techniques with ligation of vessels and biliary branches, or with an electrothermal bipolar vessel sealing system (LigaSure device). This technique is most effective for peripherally located tracts, but may be necessary for appropriate exposure of central injuries.

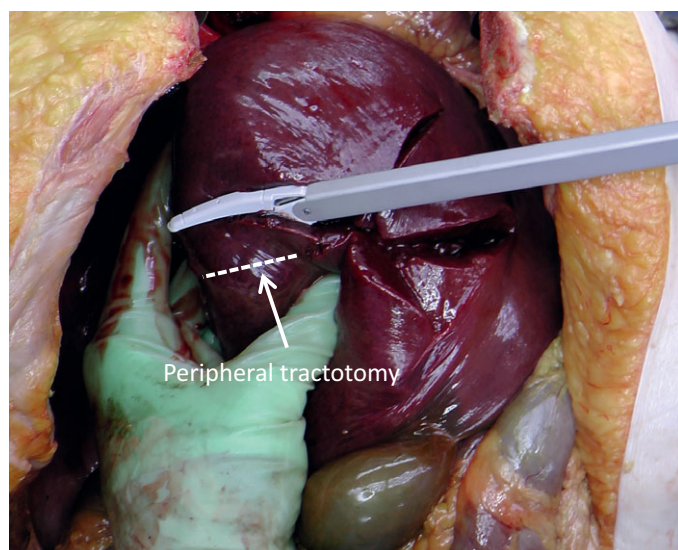
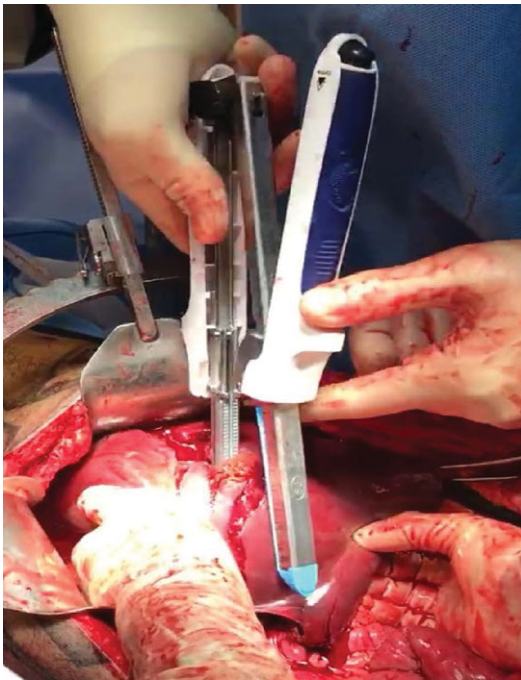
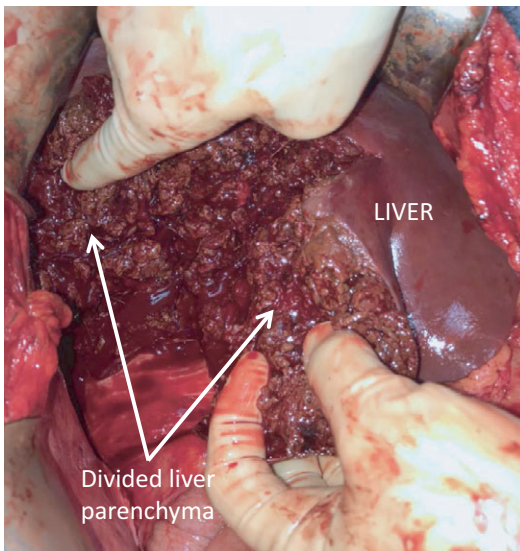


Figure 27.8 Peripheral liver tractotomy performed with electrothermal bipolar vessel sealing system.

(a)



(b)



(c)

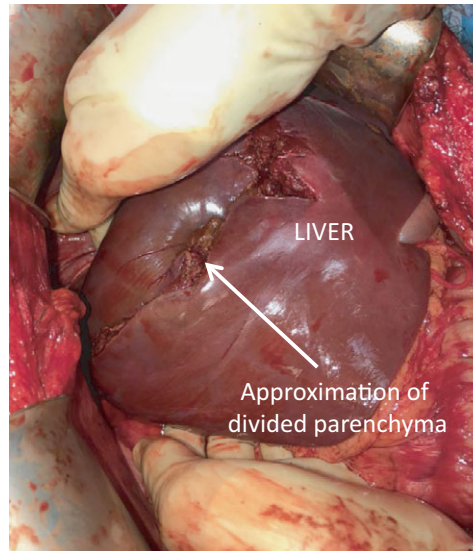


Figure 27.9 Central liver tractotomy performed with linear stapler placed within the defect, dividing the liver parenchyma to expose and control central hemorrhage (a). Completed tractotomy allowing central exposure for arterial, venous, and biliary ligation (b). Following ligation, approximation of divided liver parenchyma to assist in hemostasis and control of potential subsegmental bile leaks (c). Tissue approximation may be maintained with suture placement, perihepatic packing or absorbable mesh placement.

- For more centrally located tracts, a tractotomy will require the division of a significant volume of normal parenchyma, leading to additional bleeding, especially in a coagulopathic patient. An alternative to tractotomy is damage control tamponade using a balloon catheter. A Sengstaken and Blakemore tube designed for esophageal varices, a large Foley catheter, or a custom-made balloon from a Penrose drain or surgical glove can be used. Of these, Foley catheters are

rapidly obtainable, and are quite effective in the appropriate injury pattern. If a Foley catheter is used, however, several catheters may be required to fully fill the tract. Once the bleeding is controlled, perihepatic damage control packing is performed. The balloon is kept in place until the patient has normalized before re-exploration and possible removal. Postoperative angiographic evaluation should be considered.

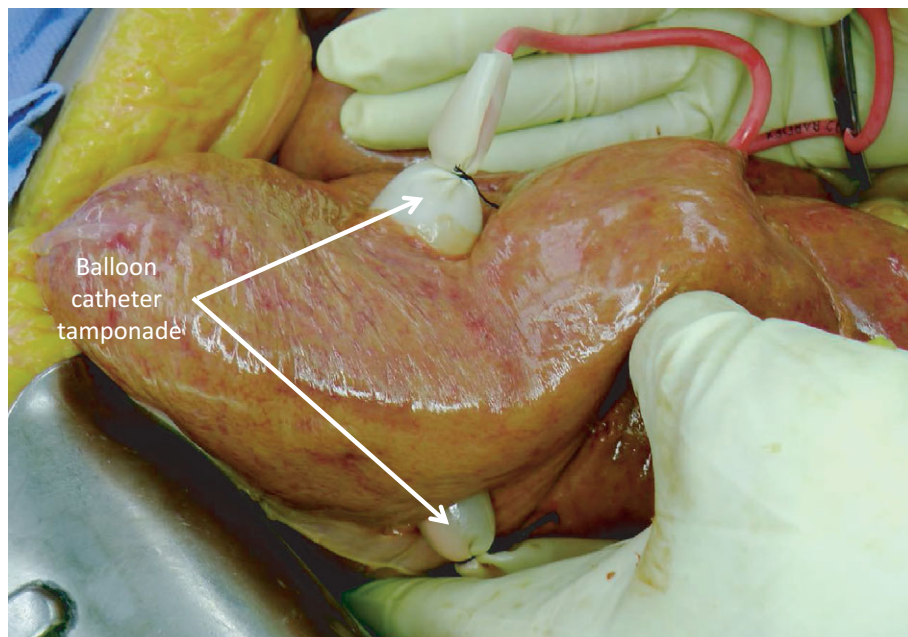


Figure 27.10 Balloon tamponade of a centrally located penetrating wound tract with a custom-made Penrose drain balloon. The balloon is left in place and the clamped catheter is externalized through the lateral abdominal wall to maintain access should deflation during subsequent angiography be necessary.

- Extensive parenchymal damage, usually due to severe blunt trauma or high-velocity gunshot wounds, is often not amenable to deep suturing. Under these conditions, the bleeding can be addressed with other techniques, including perihepatic packing, liver resection, hepatic artery ligation, total vascular liver isolation, and atriocaval shunting.
- In patients with compromised physiology and complex injuries not amenable to rapid definitive hemostasis, consider early damage control with perihepatic packing.
 - The technique of the packing is important. The presence of intact hepatic ligaments increases the effectiveness of the tamponade and they should not routinely be divided, unless necessary for adequate exposure.
- Commercially available local hemostatic products can be used if available; however, the mainstay is the use of laparotomy pads.
- In suspected retrohepatic venous bleeding, the liver should be compressed posteriorly against the IVC, with no packs placed behind the liver.
- In order to avoid bleeding from the raw surface of the liver during removal of the laparotomy pads at reoperation, an absorbable mesh may be laid over the raw surface of the liver, underneath the packing. The mesh is permanently left in place when the packing is removed.

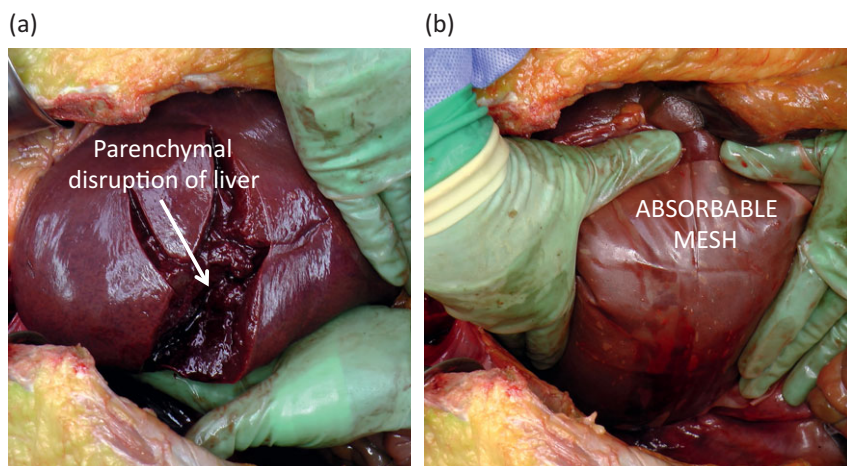


Figure 27.11 For injuries with extensive parenchymal damage (a), absorbable mesh may be placed over the surface of the liver, prior to packing (b). The mesh is permanently left in place when the packing is removed, after the patient stabilizes. This approach may reduce the risk of recurrent bleeding during pack removal.

- In cases of partial parenchymal disruption, laparotomy pads may be used for reapproximation and hemostasis.
- If packing does not control the bleeding, it is essential to unpack and look for major surgical bleeding. The patient should never leave the operating room if packing does not control the bleeding.
- Following perihepatic packing, the abdomen should always be left open, using a temporary abdominal wall closure, because of the high risk of development of abdominal compartment syndrome.
- Early postoperative angiographic evaluation for possible sites of bleeding should be considered in all cases undergoing liver packing. The availability of a hybrid operating room suite facilitates the procedure.
- The perihepatic packing should be removed as soon as the patient stabilizes physiologically, which usually occurs within 24–36 hours.
- Nonanatomical liver resection may be needed in cases with devitalized liver parenchyma or persistent bleeding, which cannot be controlled with suturing or perihepatic packing. In general, major anatomic hepatic resections are rarely indicated and should be reserved for destructive parenchymal injuries where perihepatic packing is not effective in controlling the hemorrhage.
- Nonanatomical resections can be performed with finger dissection of the parenchyma, followed by clipping or suture ligation of vessels and biliary branches, or with the use of an electrothermal bipolar vessel sealing system.
- Selective hepatic artery occlusion with a hemostatic clip may be useful in rare cases. The artery should be clipped only if temporary occlusion results in reduction of the bleeding.
- The combination of hepatic artery ligation, parenchymal injury, and hypotension often leads to hepatic necrosis, and should therefore be used only in cases of refractory bleeding.
- Ligation can also be considered for the rare occasion where there is direct injury to the hepatic artery. Shunting is an alternative damage control option that may be considered depending on the size and location of injury.

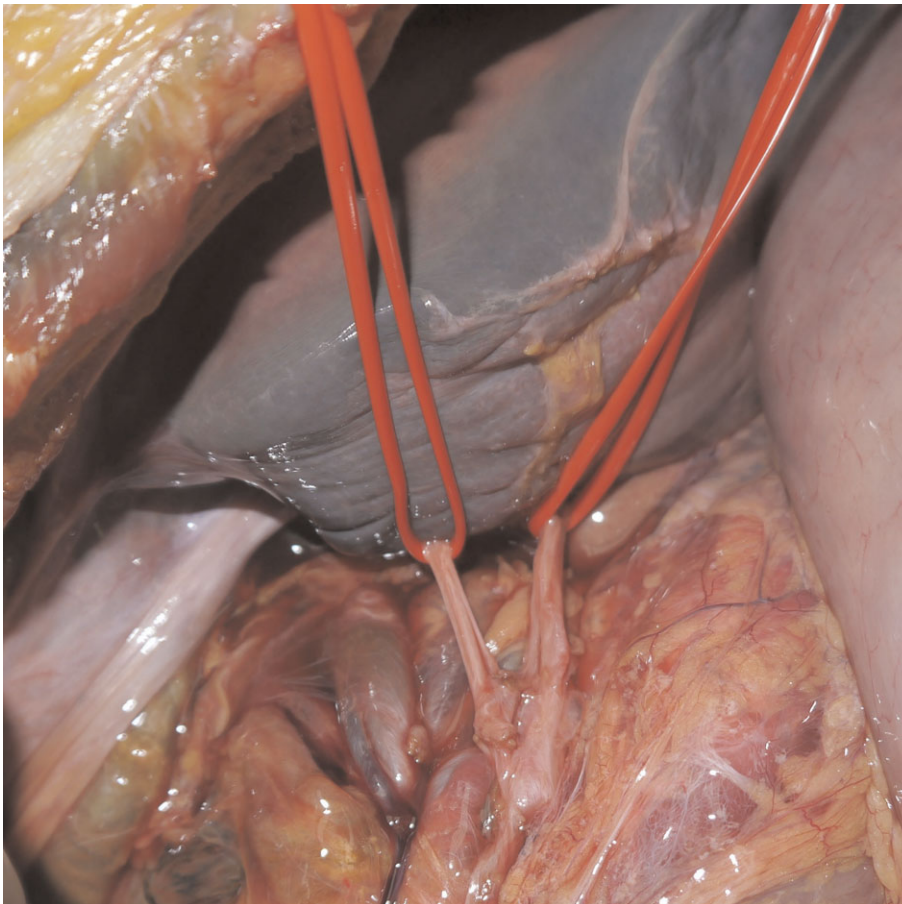


Figure 27.12 Isolation and ligation or application of a vascular clip on one of the hepatic arteries may be useful in some cases. This approach should be considered only if temporary occlusion of the artery is effective in controlling bleeding.

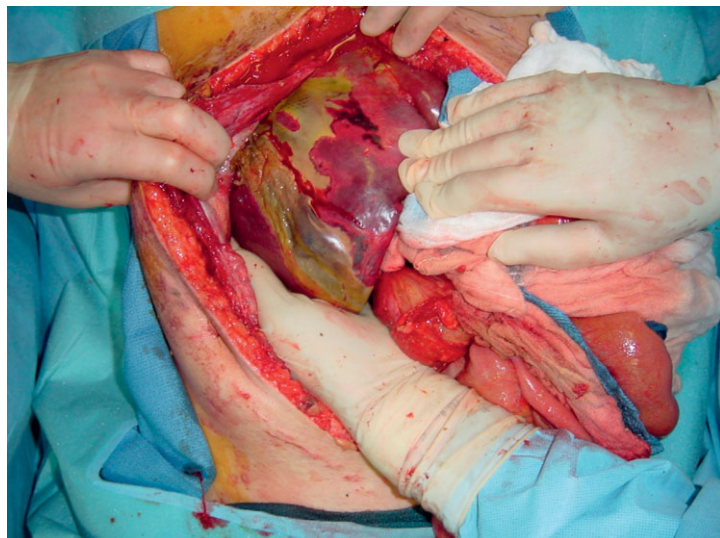


Figure 27.13 The combination of hepatic artery ligation, parenchymal injury, and hypotension often leads to hepatic necrosis.

- In cases of ineffective perihepatic packing when the injury is not amenable to resection, temporary control of the bleeding can be achieved by using total hepatic vascular isolation of the liver. This will facilitate visualization and possible repair of the area of bleeding.
 - Vascular isolation consists of occluding the aorta below the diaphragm, the suprahepatic and infrahepatic IVC, and the porta hepatis.
 - Clamping the aorta is essential and should be done first in order to prevent hypovolemic cardiac arrest.
 - Suprahepatic cross-clamping of the IVC can theoretically be performed by applying a vascular clamp

on the IVC, between the diaphragm and the dome of the liver. Practically, however, total hepatic vascular isolation is very rarely necessary because of the increased use of packing, and is employed for very severe injuries, often where the retrohepatic IVC or hepatic veins are injured. In these patients, attempting to place a clamp on the IVC in this location is extremely difficult due to the hematoma and bleeding, and there is a high probability of worsening the injury. Control of the intrapericardial IVC through a limited lower sternotomy may be preferable and safer in this situation.

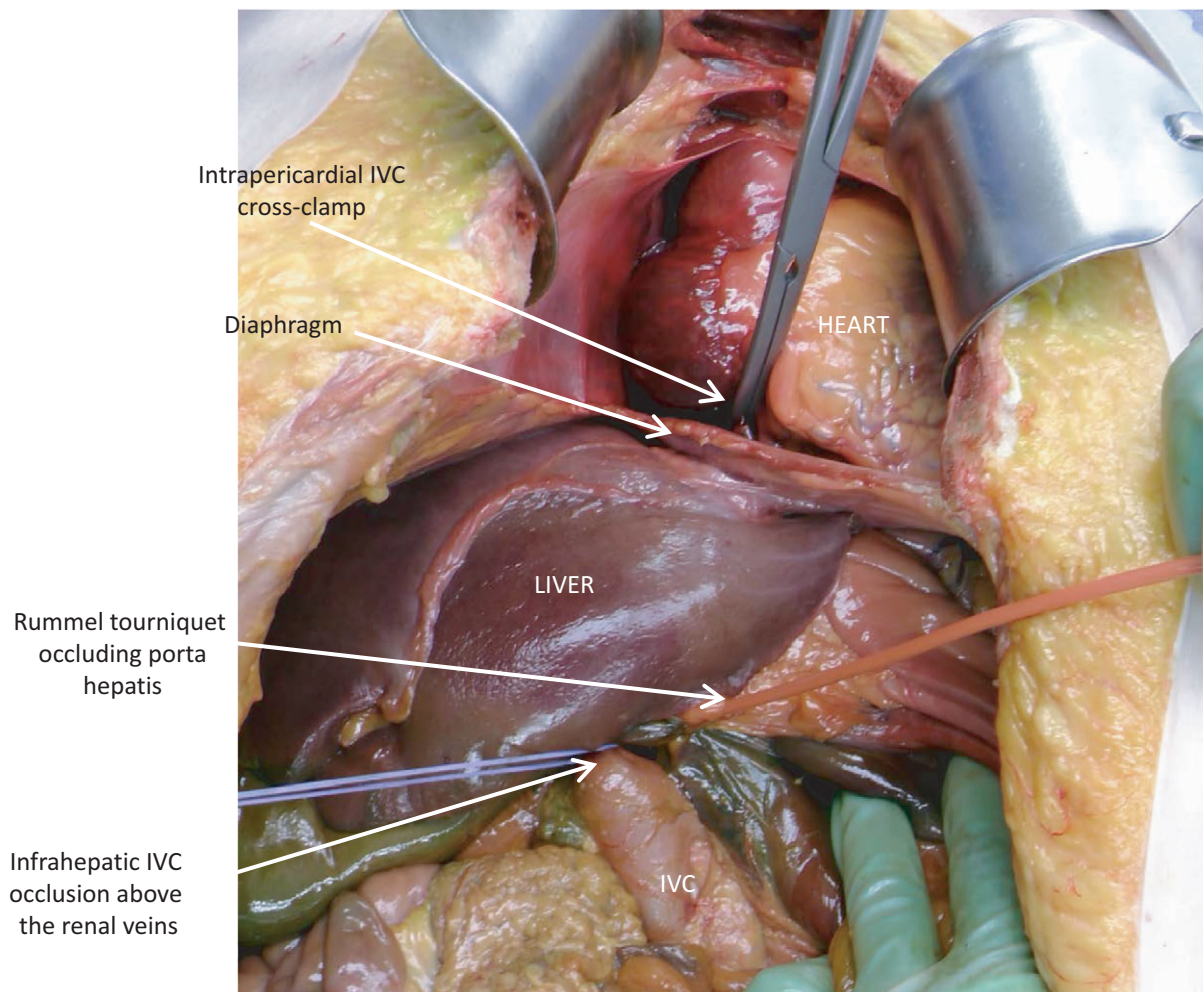


Figure 27.14 Total hepatic vascular isolation via combined midline laparotomy and sternotomy. The intrapericardial IVC is clamped with an atraumatic vascular clamp, the porta hepatis occluded with a Rummel tourniquet through the foramen of Winslow, as well as vessel loop occlusion of the suprarenal infrahepatic IVC.

- The use of atriocaval shunting may be considered in selected complex retrohepatic venous injuries that cannot be managed by other less aggressive approaches. (Details of the atriocaval shunt are shown in [Chapter 33 Inferior Vena Cava](#)).
- The atriocaval shunt reduces retrohepatic venous bleeding but does not achieve complete cessation of hemorrhage.
- The experience of the surgical team and the timing of the shunt are critical factors in determining outcome. It should be considered early, before the development of major coagulopathy and severe hypothermia.
- Management of devastating liver or avulsion injuries may require complete excision of hepatic parenchyma, rendering the patient anhepatic. Although survival in these injuries is exceptionally low, success has been

reported when followed by liver transplant. This technique should be used with extreme caution.

Extrahepatic Biliary Tract Injuries

- Most injuries to the gallbladder are best treated by cholecystectomy, although cholecystorraphy with absorbable sutures may be safely performed for small wounds.
- Injuries to the common bile duct (CBD) are difficult to repair because of the small duct size in young, healthy individuals, and a high incidence of postoperative stenosis can be expected.
 - Complete CBD transection with extensive tissue loss is best managed with a Roux-en-Y biliary enteric anastomosis.
 - Incomplete transection of the CBD may be repaired primarily. Insertion of a T-tube through a separate

choledochotomy and repair of the duct injury over the T-tube can reduce the risk of stenosis.

- In patients presenting in extremis, no definitive CBD reconstruction should be attempted. In these cases, the CBD can be ligated. Alternatively, a catheter can be placed into the proximal duct at the level of injury and brought out through the skin for external drainage. Reconstruction with a bilioenteric anastomosis is performed after patient stabilization.
- If preoperative concern exists for biliary tree injury, magnetic resonance cholangiopancreatography is recommended. If concern exists intraoperatively, cholangiogram may be performed by accessing the gallbladder or CBD for appropriate evaluation.

Postoperative Complications

- The incidence of postoperative liver-related complications in surviving patients with severe liver injuries (grades III to V) has been reported to be as high as 50%.
- These complications include early or late hemorrhage, liver necrosis, liver abscess, biloma, biliary fistula, false aneurysm, arteriovenous fistula, hemobilia, and intrahepatic biliary strictures.
- The timing of clinical presentation of liver-related complications may vary from a few days to many months. Some complications such as biloma, false aneurysm, or arteriovenous fistula may remain asymptomatic, only to manifest as potentially life-threatening complications at a later stage.
- Routine postoperative CT imaging is recommended after severe liver injury managed both operatively and nonoperatively.

Tips and Pitfalls

- The anatomical division of the liver into the eight classic Couinaud segments is practical in elective liver surgery but not in trauma.
- For approximately 80–85% of patients undergoing operation, the liver injury can be managed by relatively simple surgical techniques, such as application of local hemostatic agents, electrocoagulation, superficial suturing, or drainage. The remaining 15–20% of cases require more complex surgical techniques.
- Exposure of posterolateral liver injuries is difficult through the standard midline laparotomy. Addition of a right subcostal incision, division of the liver ligaments, and placement of laparotomy sponges behind the liver greatly improve the exposure.
- Perihepatic packing and angioembolization are significant surgical advances in the management of complex liver injuries. Consider these options early, before the patient is in extremis.
- For effective packing of suspected retrohepatic venous bleeding, no packs should be placed between the liver and IVC. The liver should be compressed posteriorly, against the IVC and hepatic veins.
- Packs placed too tightly may occlude the inferior vena cava and impair venous return leading to hemodynamic instability.
- Stable retrohepatic hematomas should not be explored. In cases with bleeding, if packing is effective, do not pursue further exploration.
- Use closed-suction drains in all complex injuries.
- Suspicion for postoperative complications in high-grade injuries, managed operatively or nonoperatively, should remain high.

Splenic Injuries

Demetrios Demetriades and Matthew D. Tadlock

Surgical Anatomy

- The spleen lies under the ninth to eleventh ribs, under the diaphragm. It is lateral to the stomach and anterosuperior to the left kidney. The tail of the pancreas is in close anatomical proximity to the splenic hilum and amenable to injury during splenectomy or hilar clamping.
- The spleen is held in place by four ligaments, which include the splenophrenic and splenorenal ligaments posterolaterally, the splenogastric ligament medially, and the splenocolic ligament inferiorly. The splenorenal ligament begins at the anterior surface of Gerota's fascia of

the left kidney and extends to the splenic hilum, as a two-layered fold that invests the tail of the pancreas and splenic vessels. The splenophrenic ligament connects the posteromedial part of the spleen to the diaphragm, and the splenocolic ligament connects the inferior pole of the spleen to the splenic flexure of the colon. The splenogastric ligament is the only vascular ligament and contains five to seven short gastric vessels that originate from the distal splenic artery and enter the greater curvature of the stomach. Excessive retraction of the splenic flexure or the gastrosplenic ligaments can easily tear the splenic capsule and cause troublesome bleeding.

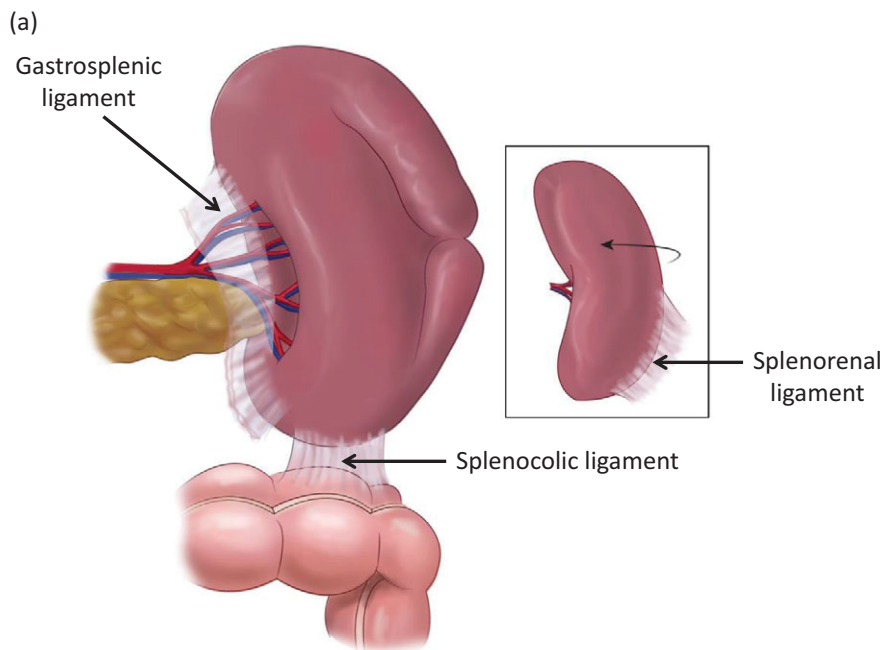
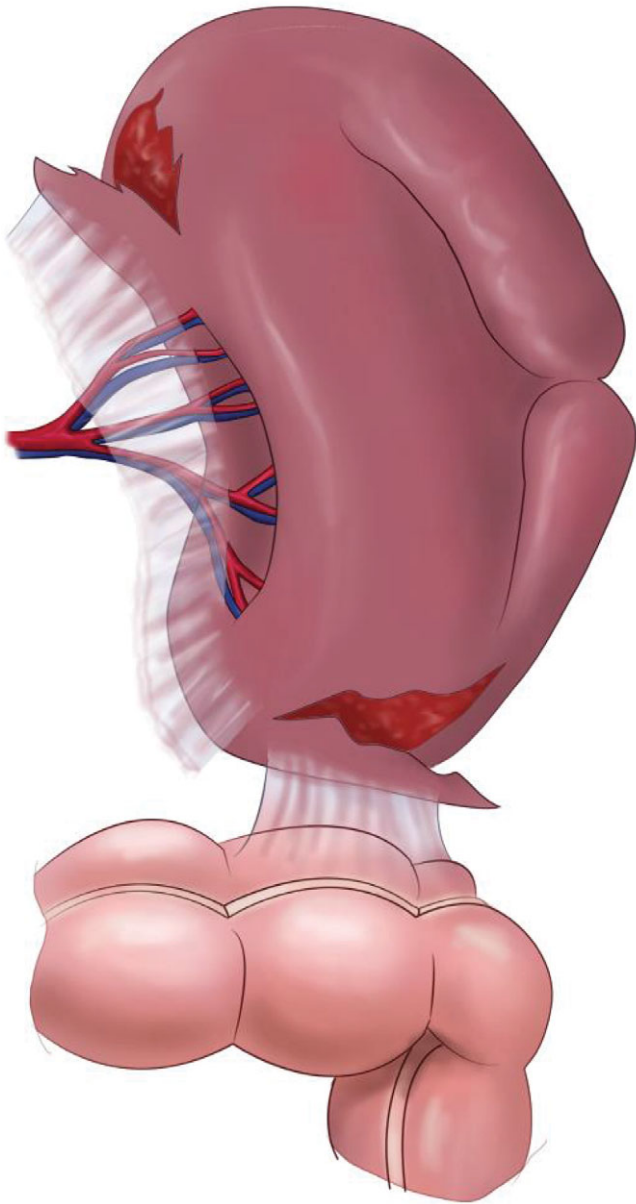
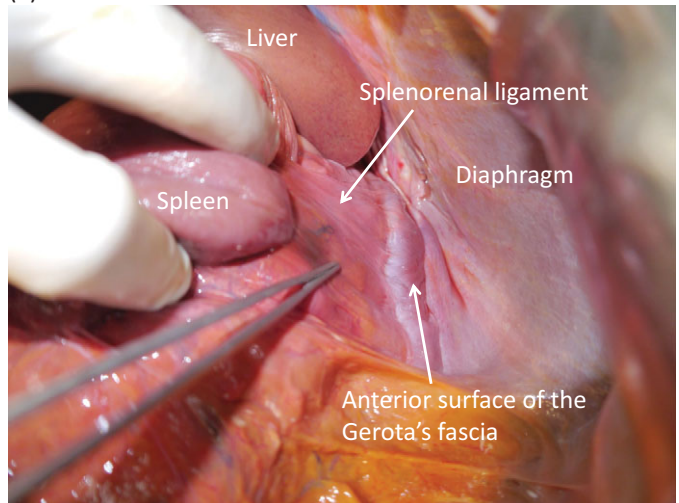


Figure 28.1 (a) The spleen is held in place by four ligaments: the splenophrenic and splenorenal ligaments posterolaterally, the splenogastric medially, and the splenocolic inferiorly. Medial rotation of the spleen (inset) exposes the splenophrenic and splenorenal ligaments. (b) Undue traction on the spleen, the stomach, or the colon may cause capsular avulsion and bleeding.

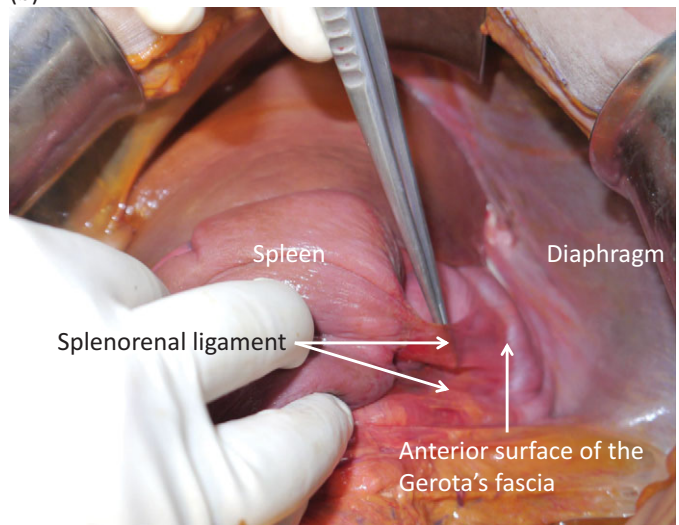
(b)

**Figure 28.1** (cont.)

(a)



(b)

**Figure 28.2 (a, b)** Medial rotation of the spleen exposes the splenorenal ligament, which begins at the anterior surface of the Gerota's fascia of the left kidney and extends to the splenic hilum.

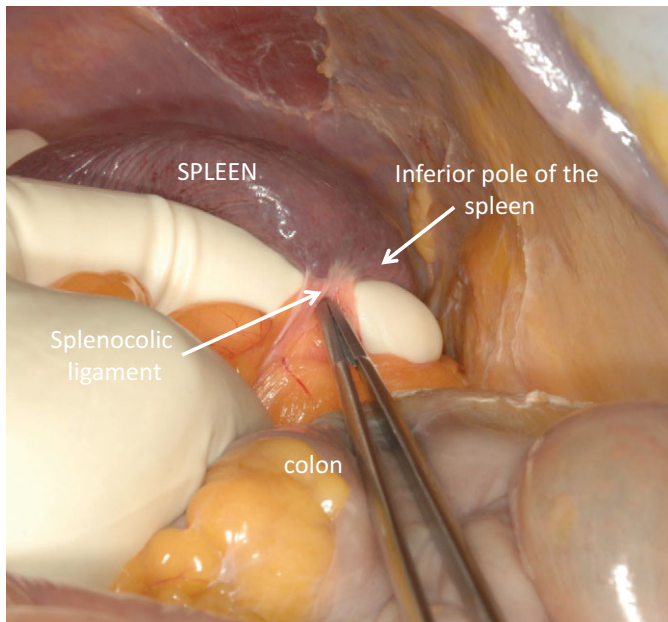


Figure 28.3 The splenocolic ligament connects the inferior pole of the spleen to the splenic flexure of the colon, and is avascular. Excessive traction may cause capsular avulsion and bleeding.

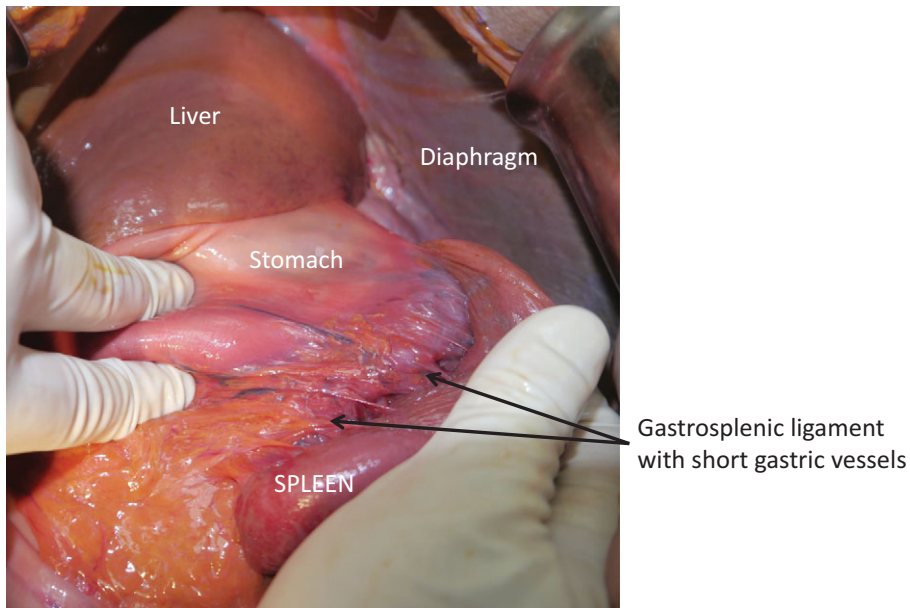


Figure 28.4 The stomach is retracted medially and the spleen laterally revealing the gastrosplenic ligament and the short gastric vessels.

- The mobility of the spleen depends on the architecture of these ligaments. In patients with short and well-developed ligaments, mobilization is more difficult and requires careful dissection in order to avoid further splenic damage.
- The splenic hilum contains the splenic artery and vein and is often intimately associated with the tail of the pancreas. The extent of the space between the tail of the pancreas and the splenic hilum varies from person to person.
- The splenic artery is a branch of the celiac axis that courses superior to the pancreas towards the splenic hilum where it divides into upper and lower pole arteries. There is significant variability in where this branching occurs. Most people, approximately 70%, have a distributed or medusa like branching that occurs 5–10 cm from the spleen. Simple branching occurs in approximately 30%, 1–2 cm from the spleen.
- The splenic vein courses posterior and inferior to the splenic artery, receives the inferior mesenteric vein, and joins the superior mesenteric vein to form the portal vein.

General Principles

- The spleen is the second most commonly injured abdominal solid organ after blunt trauma and the second most commonly injured after penetrating trauma.
- Nearly 80% of patients with splenic injury after blunt trauma can be managed nonoperatively, but only if they are hemodynamically stable with a stable hemoglobin and without peritonitis. Nonoperative management of splenic injuries is ill-advised in patients with a significant injury burden, coagulopathy, or severe traumatic brain injury.
- Angioembolization is an adjunct to the nonoperative management of high-grade splenic injuries, especially in patients with evidence of active extravasation on contrast-enhanced CT scan.
- All patients who undergo emergent splenectomy should receive vaccinations for encapsulated organisms prior to hospital discharge.

Special Surgical Instruments

- A standard trauma laparotomy tray, which includes vascular instruments.
- A fixed self-retaining retractor, such as a Bookwalter retractor, is very helpful.
- An electrothermal bipolar vessel sealing system device (LigaSure device) is desirable.
- An absorbable mesh or preformed mesh splenic pouch should be available in cases where splenic preservation is to be attempted.

Positioning and Incision

- The patient should be placed in the supine position with arms out and prepped from nipples to knees. For trauma, entry into the abdomen should be through a midline incision, starting high, at the xiphoid process.

Exposure

- Upon entry into the peritoneal cavity, the surgeon often encounters a significant amount of blood. The blood should be removed quickly and the left upper quadrant packed with laparotomy pads to temporarily control the bleeding.
- The next step is full exposure and inspection of the spleen in order to plan the definitive management of the injury. The surgeon should slide his right hand gently over the posterolateral surface of the spleen and exert slight medial and downward traction. Three or four laparotomy pads are then placed under the left diaphragm and behind the spleen. This maneuver provides excellent exposure of the spleen.

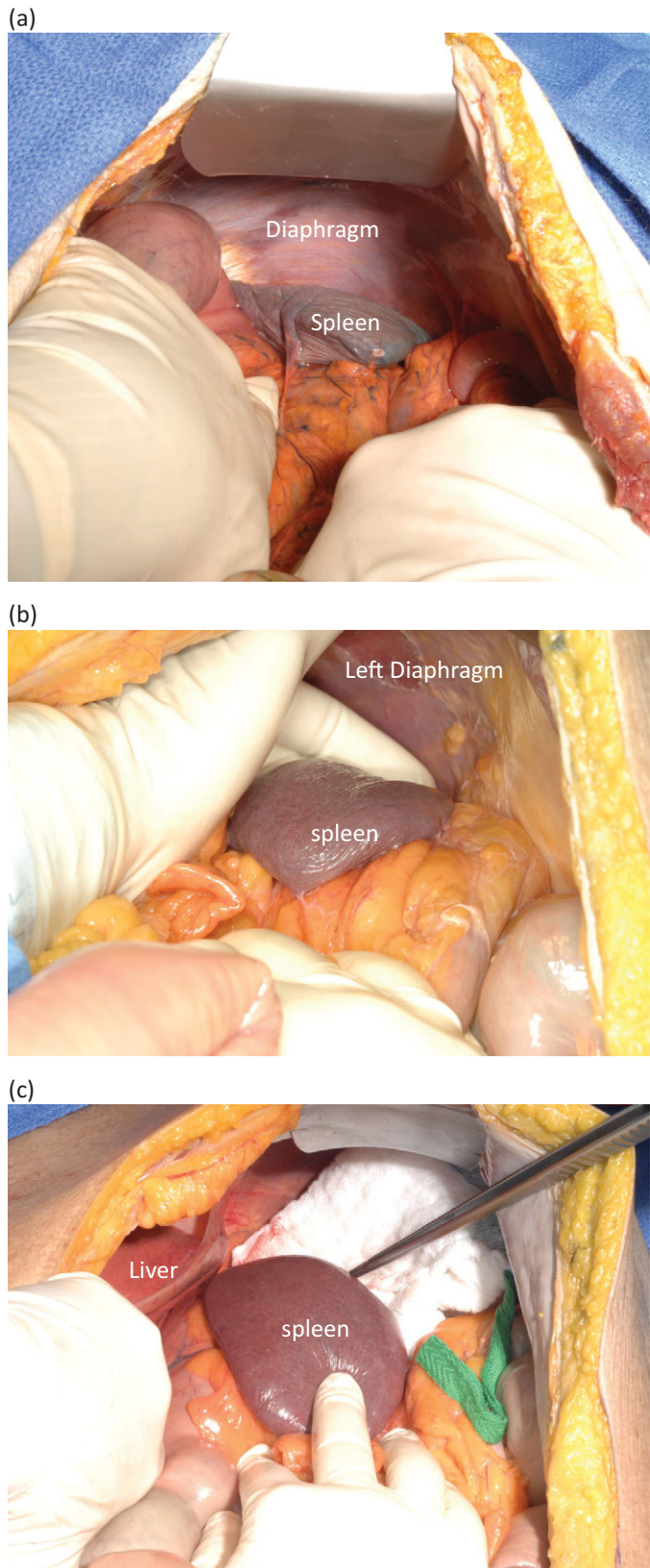


Figure 28.5 (a) View of the spleen, deep in the left hypochondrium, from the right side of the operating room table. Note the deep and posterior position of the spleen, which makes exposure difficult. (b) With the surgeon's left hand, the spleen is gently rotated medially and downward to facilitate placement of laparotomy pads. (c) Laparotomy pads are placed above and behind the spleen, to keep the spleen in a downward and medial position. Note the significantly improved exposure.

- The surgeon should be gentle during exposure of the spleen because undue traction on the stomach or the splenic flexure of the colon or excessive medial rotation of the spleen may cause avulsion of the delicate splenic capsule, aggravating the bleeding and decreasing the possibility of splenic preservation.
- Profuse bleeding can temporarily be controlled with digital compression of the hilum between the second and third fingers of the surgeon's left hand or direct digital compression of the splenic parenchyma. A vascular clamp can also be placed across the hilum, taking care not to injure the tail of the pancreas.
- Mobilization of the spleen is not necessary for simple repairs, and in some cases, it may worsen the splenic injury.
- In order to facilitate splenectomy or complex splenic preservation operations using splenic mesh or partial splenectomy, the spleen should be adequately mobilized. The first step is division of the splenophrenic and splenorenal ligaments posterolaterally. These ligaments are avascular and can be divided sharply. The next step is the en-block medial mobilization of the spleen and the tail of the pancreas. Mobilization of the tail of the pancreas may not be necessary in patients with a short pancreas and a long distance between the tail and the hilum. The next step is division of the vascular gastrosplenic ligament, as far away from the stomach as possible in order to avoid injury or ischemic necrosis of the gastric wall. The final step is division of the splenocolic ligament. Although this stepped approach for the mobilization of the spleen is applicable to most patients, the surgeon should have in mind that the order of taking down the splenic ligaments should be flexible and determined by the local anatomy and may vary from patient to patient. For the patient with a partially avulsed spleen that is actively hemorrhaging, rapid hilar vascular control takes precedence over meticulous ligament identification and division.

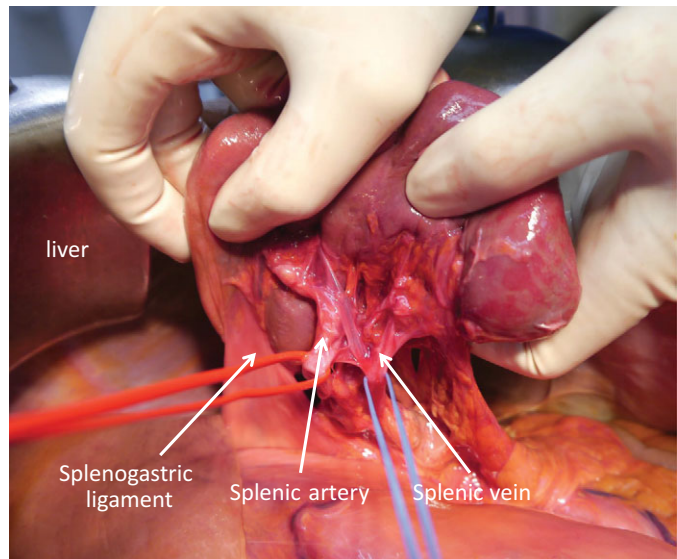


Figure 28.6 The spleen is mobilized, reflected medially, and the splenic vessels dissected.

- Once adequate exposure is obtained, the salvageability of the spleen is assessed.

Splenectomy

- The first step is adequate mobilization of the spleen and delivery of the spleen towards the midline. Temporary bleeding control and division of the ligaments are performed as described. The short gastric vessels in the gastrosplenic ligament should be ligated away from the stomach in order to avoid damage or ischemic necrosis of the gastric wall. An electrothermal bipolar vessel sealing system, such as the LigaSure device, may be used as a safe and faster alternative to vessel ligation and division.
- The spleen now is attached only by the splenic vessels, along with the tail of the pancreas, at the hilum.

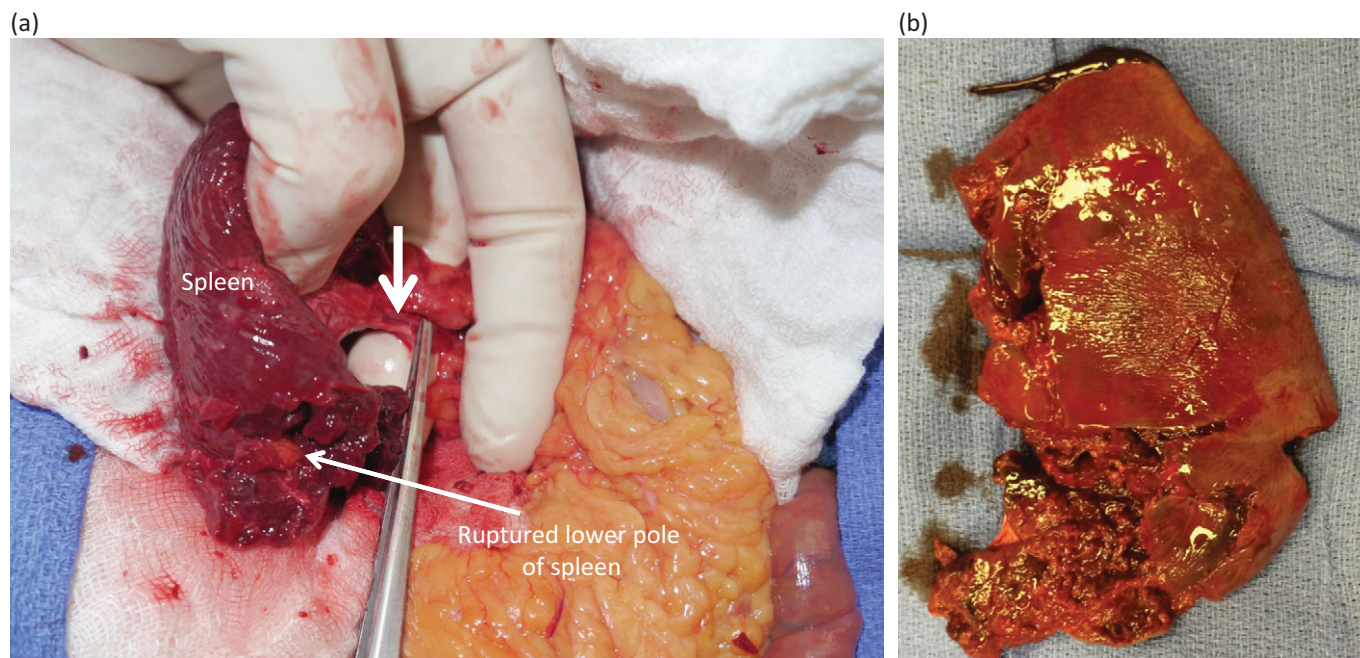


Figure 28.7 After division of the splenic ligaments and medial rotation, the spleen remains attached only by the splenic vessels (thick arrow). Temporary bleeding control is achieved by compressing the hilar structures between the fingers (a). Splenectomy specimen (b).

- The splenic artery and vein should be individually ligated as close to the hilum as possible to avoid injuring the pancreas. Use of an electrothermal bipolar vessel sealing system is an alternative to ligation and division of the vessels.
- Occasionally, the splenic hilum and tail of the pancreas are so intimately related that a small portion of the distal

pancreas may need to be resected to safely perform the splenectomy. This can be done with a TA stapling device or electrothermal bipolar vessel sealing system. In these cases, care should be taken to ensure hemostasis of the superior pancreatic artery that runs along the superior portion of the pancreas.

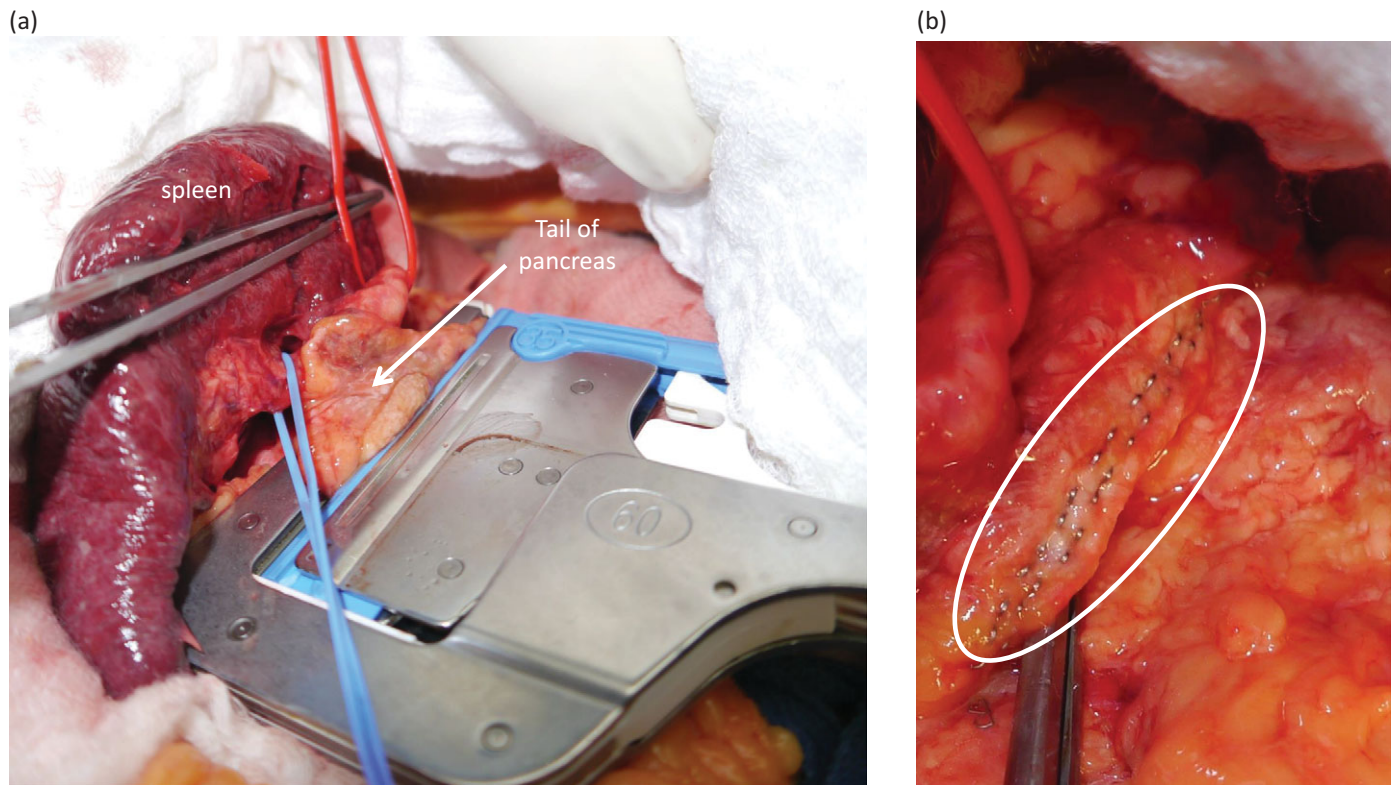


Figure 28.8 Stapled splenectomy technique: Sometimes the tail of the pancreas is so intimately related to the splenic hilum that it may be necessary to remove a small part of the pancreas with the spleen. A stapled en masse resection is an effective resection technique (The splenic artery is shown encircled with a red vessel loop and the splenic vein with a blue vessel loop) (a). Stapled off pancreatic tail (circle) (b)

- Mass ligation of the artery and vein together may be considered in unstable patients, although there is concern about the rare complication of arteriovenous fistula.
 - After the removal of the spleen, meticulous hemostasis should be performed. The most common sites of incomplete hemostasis are the areas near the tail of the pancreas and the greater curvature of the stomach, at the insertion of the short gastric vessels. The stomach should be inspected for any ischemic damage. Likewise, the tail of the pancreas should also be examined for any iatrogenic injury.
 - In a damage control setting, there is no role for spleen-preserving operations. The splenic bed is at risk of bleeding and should be packed with several laparotomy pads.
 - Although the routine placement of closed suction drains in the splenic bed is a controversial issue, it is advisable to place a closed drain in cases where there is concern about incomplete hemostasis or possible injury to the tail of the pancreas.
- ### Splenorrhaphy
- The size, site, and shape of the splenic injury and the hemodynamic condition of the patient will determine the feasibility of a spleen-preserving operation.
 - For capsular avulsions or superficial parenchymal lacerations, there is no need for full splenic mobilization with division of the splenic ligaments. Placement of two to three laparotomy pads behind the spleen usually provides adequate exposure.
 - For complex repairs, full mobilization of the spleen, as described above, may be necessary.
 - In cases with avulsion of the splenic capsule or minor lacerations, hemostasis can be achieved with local hemostatic agents.
 - Superficial lacerations may be repaired with figure-of-eight or horizontal mattress absorbable sutures, on a blunt liver needle. The presence of an intact splenic capsule makes the placement of the sutures technically easier because it prevents tearing of the parenchyma. If the parenchyma is fragile and does not hold sutures, pledgets may be used.

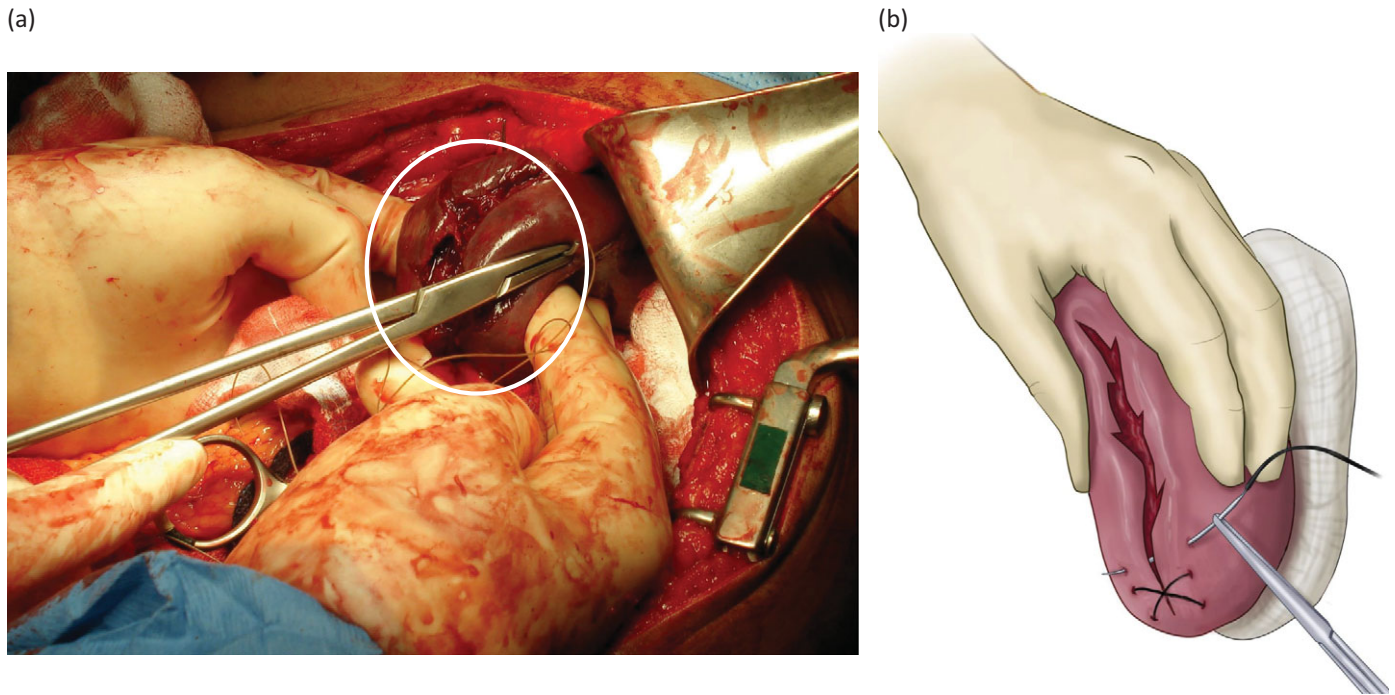


Figure 28.9 (a, b) Splenorrhaphy: Digital compression of the injured spleen (circle) provides temporary bleeding control and repair of the laceration with figure-of-eight sutures.

- In deep lacerations with active bleeding, temporary control may be achieved by finger compression of the injured site or the hilum. Any major bleeders are suture-ligated individually and the laceration is then repaired with interrupted figure-of-eight sutures, as described above. Failure to individually ligate any major bleeders before suturing a deep laceration may result in intrasplenic hematoma or false aneurysm. An omental patch may be sutured into areas with tissue loss.

Partial Splenectomy

- A partial splenectomy is possible because of the segmental blood supply of the spleen, with the vessels travelling in a parallel fashion. It should be considered in injuries localized to either the upper or lower pole of the spleen.
- Full splenic mobilization, as described above, is essential before attempting partial splenic resection.
- If the individual vessels to the injured pole can be identified, they should be ligated at the hilum before entering the spleen, for better hemostasis.

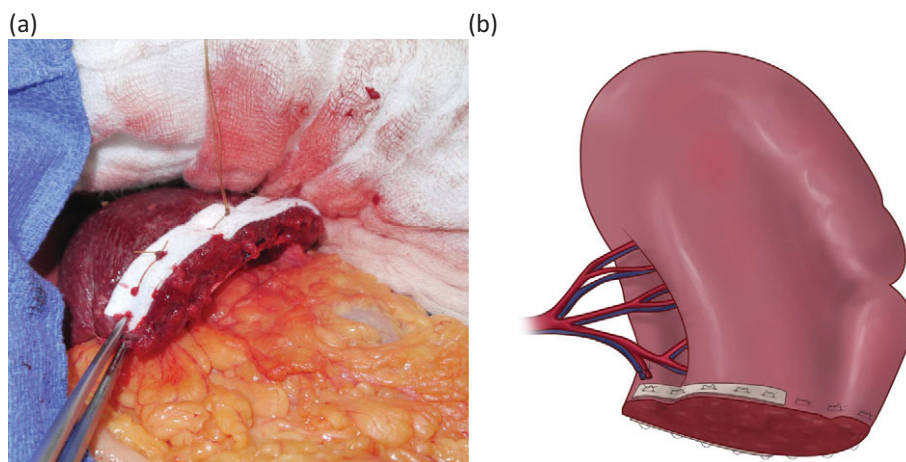


Figure 28.10 (a, b) Partial splenectomy. The procedure may be performed with finger dissection and ligation of individual intrasplenic vessels or electrothermal bipolar vessel sealing system (LigaSure device) or a TA stapling device. Ligation of segmental vessels in the hilum reduces bleeding. Vertical mattress sutures with pledgets may be used for persistent oozing from the cut edge.

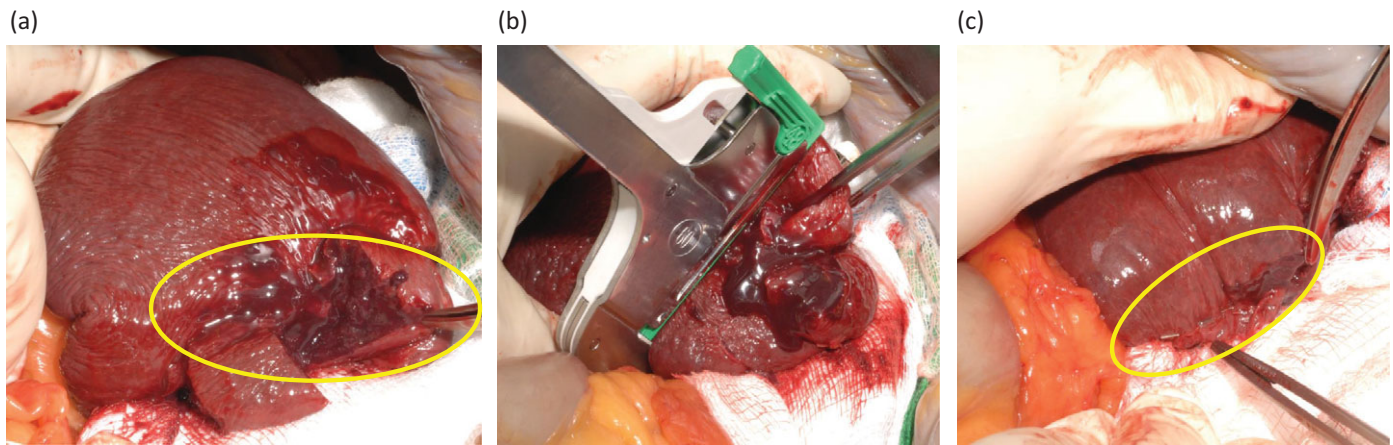


Figure 28.11 Partial splenectomy of the lower pole with a TA-90 stapler; Injury to the inferior pole of the spleen, not amenable to repair (circle) **(a)**. Application of TA-90 stapler proximal to the injured inferior pole **(b)**. Completion of partial splenectomy with complete hemostasis **(c)**.

- A capsular incision is made with electrocautery, parallel to the lobar arteries. Using blunt finger dissection or fine tipped suction, the underlying parenchyma of the avascular tissues is divided and individual intrasplenic vessels are identified and ligated with a 3-0 or 4-0 silk. Alternatively, an electrothermal bipolar vessel sealing system (LigaSure device) or a TA stapling device may be used.
- If there is persistent oozing from the cut edges, hemostatic vertical mattress sutures may be applied, with or without pledgets.

Splenic Mesh

- An absorbable mesh can also be utilized for splenic salvage in cases with multiple stellate parenchymal injuries or extensive avulsion of the splenic capsule.
- Bean-shaped mesh pouches are commercially available, or a mesh wrap can be constructed by the surgeon. Local hemostatic agents may be used as adjuncts to the mesh.

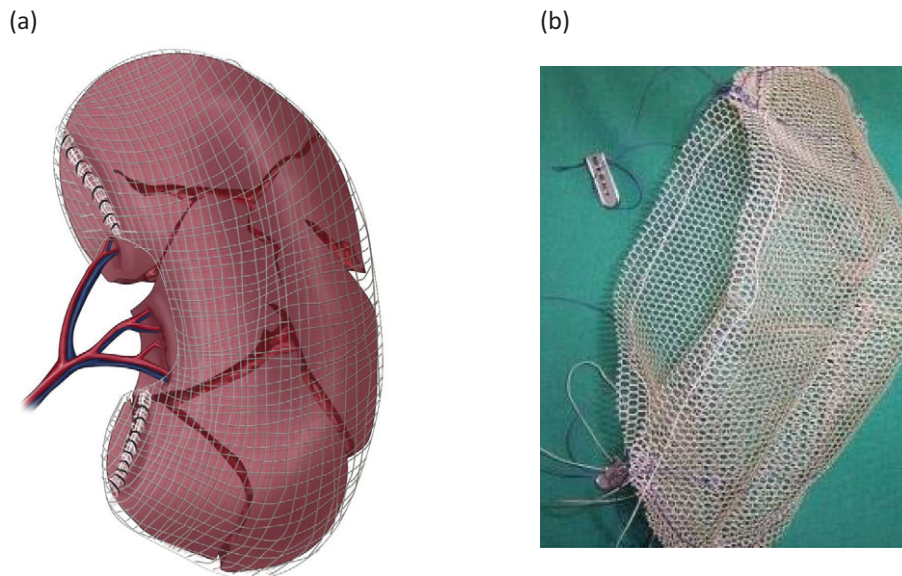


Figure 28.12 Application of a splenic mesh may be a good adjunct in splenic preservation operations in multiple stellate parenchymal lacerations or extensive capsular avulsion **(a)**. Commercially available splenic mesh **(b)**.

Tips and Pitfalls

- Nonoperative management of severe blunt splenic injuries in patients with traumatic head injury or coagulopathy is generally not recommended.
- Splenic salvage is a reasonable option in stable patients, if the injury is amenable to simple repair, splenic mesh, or partial splenectomy. In unstable or coagulopathic patients, splenectomy is the procedure of choice.
- Full mobilization of the spleen is mandatory before attempting splenorrhaphy of deep or complex lacerations, placement of a splenic mesh, or a partial splenectomy. Mobilization of the spleen improves the exposure, but it has the potential of making the injury worse, if done incorrectly.
- During splenectomy, ligation of the short gastric vessels should be performed close to the spleen to avoid damage to the greater curvature of the stomach. These vessels can be very short, and there is little or no space between the stomach and the spleen. In these cases, leave a thin rim of splenic tissue distally. If there is concern about damage to the stomach, it is advisable to oversew the area with Lembert sutures.
- During splenectomy, the splenic vessels should be ligated very close to the spleen to avoid injury to the tail of the pancreas. If a rim of pancreatic tissue has to be removed with the spleen, suture ligate or use an electrothermal bipolar vessel sealing system to prevent pancreatic leaks or bleeding from the superior pancreatic artery.
- The most common sites of persistent postoperative bleeding are the areas near the tail of the pancreas, from the superior pancreatic artery and at the insertion of the short gastric vessels into the stomach.
- All severe splenic injuries managed with splenic preservation should undergo a postoperative CT scan with intravenous contrast to rule out false aneurysms or arteriovenous fistulas.
- Remember to vaccinate splenectomy patients for encapsulated organisms prior to discharge.

Pancreas

Demetrios Demetriades, Emilie Joos, and George C. Velmahos

Surgical Anatomy

- The pancreas lies transversely in the retroperitoneum, at the L₁–L₂ vertebral level, between the duodenum and the hilum of the spleen.
- The head of the pancreas lies over the inferior vena cava (IVC), right renal hilum, and the left renal vein at its junction with the IVC.
- The uncinate process extends to the left and wraps from around the superior mesenteric vessels. It is in close proximity to the inferior pancreaticoduodenal artery.
- The neck of the pancreas lies over the superior mesenteric vessels and the proximal portal vein. The space between the neck and the superior mesenteric vessels is avascular and allows blunt dissection without bleeding. The area to either side of the midline is vascular and should be avoided.
- The body of the pancreas lies over the suprarenal aorta and the left renal vessels. It is intimately related to the splenic artery and vein.
- The major pancreatic duct (Wirsung) traverses the entire length of the pancreas and drains into the ampulla of Vater, approximately 8 cm below the pylorus. The lesser duct of Santorini branches off the superior aspect of the major duct, at the level of the neck of the pancreas, and drains separately into the duodenum, approximately 2–3 cm proximal to the ampulla of Vater.
- The pancreas receives its blood supply from both the celiac artery and the superior mesenteric artery.
 - The head of the pancreas and the proximal part of the duodenum receive their blood supply from the anterior and posterior pancreaticoduodenal arcades. These arcades lie on the surface of the pancreas, close to the duodenal loop. Any attempts to separate the two organs results in ischemia of the duodenum.
 - The body and tail of the pancreas receive their blood supply mainly from the splenic artery. The splenic artery originates from the celiac artery and courses to the left along the superior border of the pancreas. It follows a tortuous route, with parts of it looping above and below the superior border of the pancreas. It gives numerous small and short branches to the body and tail of the pancreas.
 - The splenic vein courses from left to right, superiorly and posteriorly to the upper border of the pancreas, inferiorly to the splenic artery. It is not tortuous like the artery. It joins the superior mesenteric vein, at a right angle, behind the neck of the pancreas, to form the portal vein. The inferior mesenteric vein crosses behind the body of the pancreas and drains into the splenic vein.
- The portal vein is formed by the junction of the superior mesenteric and splenic veins, in front of the inferior vena cava and behind the neck of the pancreas.
- The common bile duct (CBD) courses posterior to the first part of the duodenum, in front of the portal vein, continues behind the head of the pancreas, often partially covered by pancreatic tissue, and drains into the ampulla of Vater, in the second part of the duodenum.

General Principles

- The management of pancreatic trauma is determined by the presence or absence of pancreatic duct injury. Patients

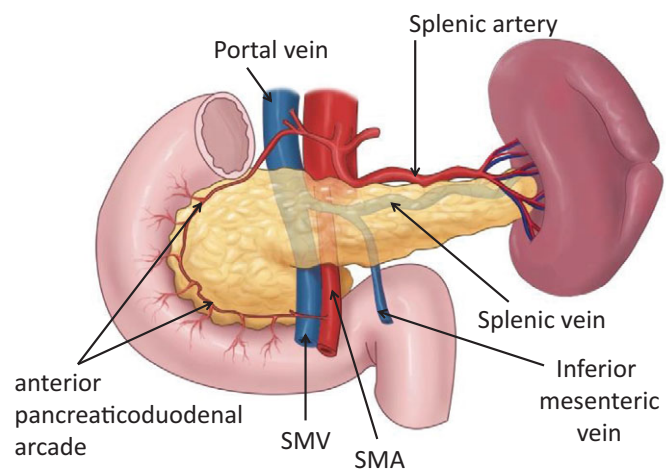


Figure 29.1 Surgical anatomy of the pancreas. The head of the pancreas and the proximal part of the duodenum share blood supply from the anterior and posterior pancreaticoduodenal arcades. SMA, superior mesenteric artery; SMV, superior mesenteric vein.

with pancreatic contusions or lacerations without duct involvement may be managed nonoperatively. If these injuries are discovered during the operation, drainage with closed suction drain is usually sufficient. Conversely, almost all patients with pancreatic duct transection require operative management and pancreatic resection.

- The pancreas is surgically divided into a distal and proximal part. The distal pancreas consists of all pancreatic tissue (body and tail) to the left of the superior mesenteric vessels. The proximal pancreas is composed of all pancreatic tissue (head and neck) to the right of the superior mesenteric vessels.
 - In distal pancreatic injuries involving the pancreatic duct, a distal pancreatectomy is the procedure of choice. A spleen-preserving distal pancreatectomy can be considered in stable patients. However, in the presence of severe associated injuries or hemodynamic instability, a distal pancreatectomy with splenectomy should be performed because it is a much faster and easier procedure.
 - Distal pancreatectomy rarely results in permanent diabetes or pancreatic exocrine insufficiency. Hyperglycemia may be observed in the early postoperative period, but it usually resolves spontaneously.
 - For injuries involving the head of the pancreas, if the integrity of the duct cannot be confirmed, pancreatic drainage alone should be considered. Postoperative evaluation of the integrity of the pancreatic duct should be performed by CT scan or magnetic resonance cholangiopancreatography (MRCP) and, in selected cases, with endoscopic retrograde cholangiopancreatography (ERCP). Radical resections should be avoided because of the associated high morbidity and mortality.
 - Freeing of the lateral aspect of the head of the pancreas from the duodenum results in ischemia of the duodenum and it should never be done.
 - Pancreaticoduodenectomy should rarely be considered because of its complexity and the associated high morbidity and mortality. It should be considered primarily in cases with severe combined pancreaticoduodenal trauma.
 - In cases with pancreatic injury selected for nonoperative management, evaluation by means of ERCP or MRCP is important in order to assess the integrity of the pancreatic duct. In addition, for selected

cases with partial pancreatic duct injury, ERCP can be used for therapeutic stent placement.

- Missed pancreatic injuries with ductal involvement may result in complications such as pancreatitis, pancreatic ascites, pancreatic pseudocyst, abscess, or erosion of the adjacent vessels with life-threatening bleeding.
- Pancreatic injuries without ductal involvement rarely cause significant problems and do not require operation.

Special Surgical Instruments

- Standard exploratory laparotomy tray can be used for this approach
- Self-retaining Bookwalter or Omni-flex retractor can greatly facilitate surgical exposure
- Headlamp

Positioning

- The patient should be in supine position, with arms abducted at 90°. Preparation and draping should be done in the usual fashion.

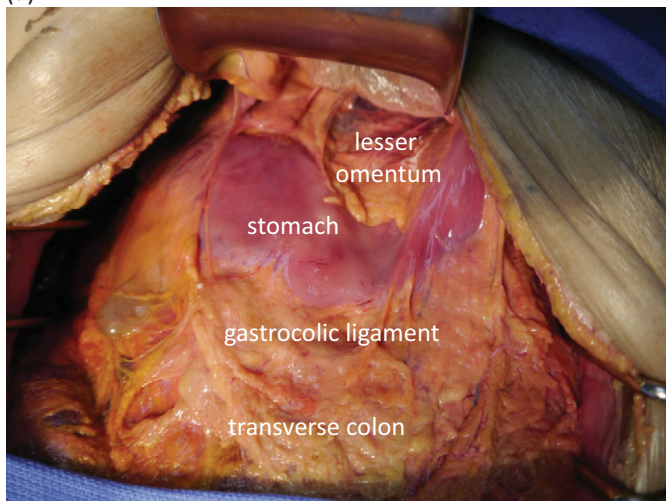
Incision

- A standard midline trauma laparotomy incision.

Exposure

- Intraoperatively, pancreatic injury should be suspected by the presence of fluid collection or hematoma in the lesser sac, and in delayed diagnosis cases, by inflammation or fat necrosis of the surrounding tissues.
- Most of the pancreas can be exposed through the lesser sac. The stomach is retracted upwards and towards the patient's head and the transverse colon is retracted towards the pelvis. The gastrocolic ligament is divided, starting from the left side, where the ligament is usually thin and transparent. An electrothermal bipolar vessel sealing system (LigaSure device) may be used as a safe and rapid alternative to vessel ligation and division. The lesser sac is then entered and any attachments between the pancreas and the posterior wall of the stomach are divided. This approach exposes the anterior, superior, and inferior surfaces of the body and tail of the pancreas.
- The superior mesenteric vessels exit from the inferior border of the neck of the pancreas, and the uncinate process of the pancreas extends to the left and wraps around the superior mesenteric vessels. Care should be taken to avoid injury during exploration of this area.

(a)



(b)

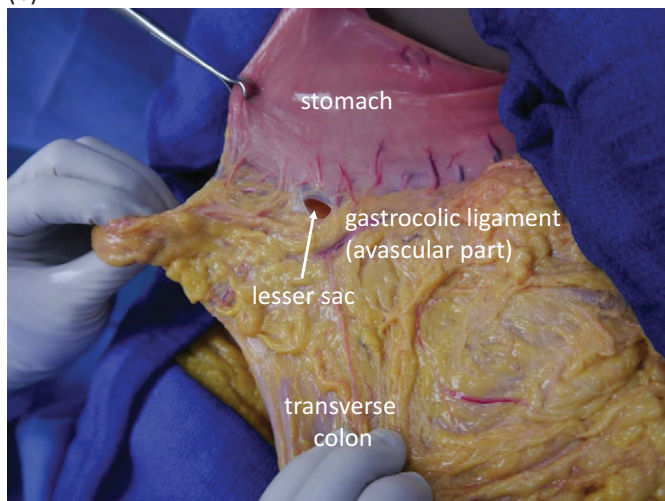


Figure 29.2 (a) Exposure of the pancreas through the lesser sac. The stomach is retracted upwards and towards the patient's head and the transverse colon is retracted towards the pelvis. The gastrocolic ligament is divided and the lesser sac is entered. (b) Entering into the lesser sac through the gastrocolic ligament. The left side of the ligament is usually thin and transparent and easier to enter into the lesser sac through its area (arrow).

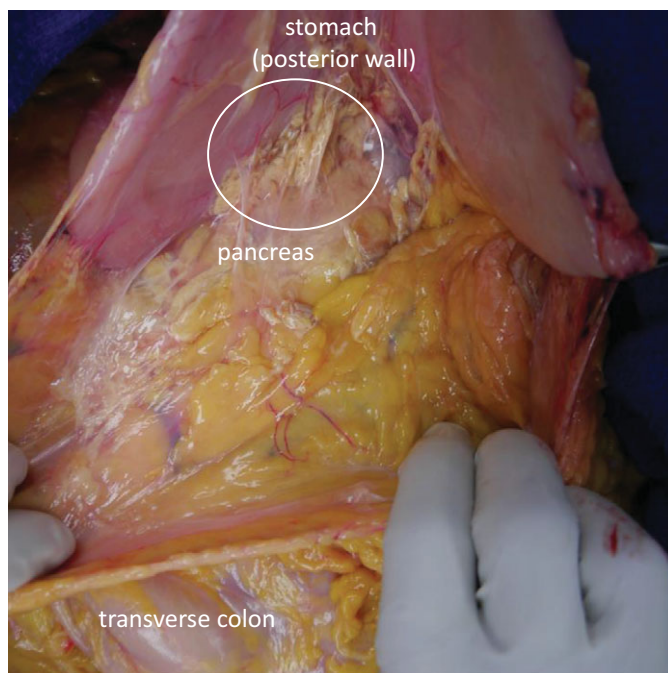


Figure 29.3 After entering the lesser sac, any attachments between the pancreas and the posterior wall of the stomach (circle) are divided.

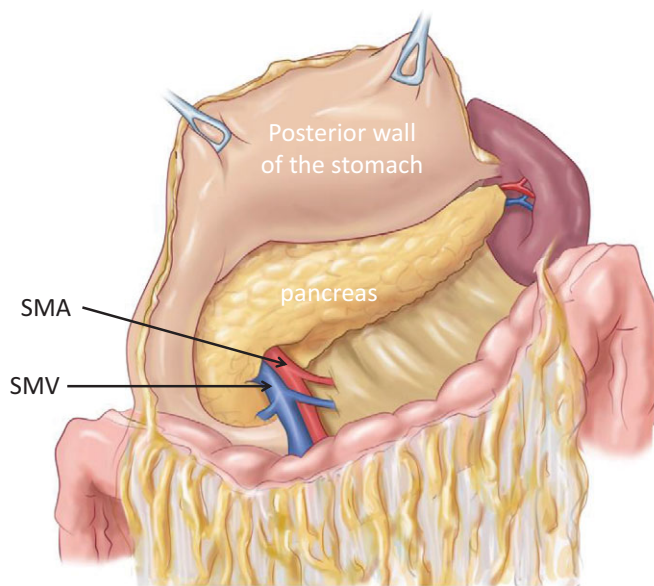


Figure 29.4 Complete exposure of the body and tail of the pancreas, after opening the lesser sac. Care should be taken to avoid injury to the superior mesenteric vessels during exploration of the area near the neck. SMA, superior mesenteric artery; SMV, superior mesenteric vein.

- The posterior pancreas can be inspected by incising the peritoneum over the inferior border of the pancreas and gentle upwards retraction. In cases where a detailed examination of the posterior distal pancreas is required, the spleen and tail of the pancreas are mobilized and retracted medially en bloc (see [Chapter 28 Splenic Injuries](#)).
- The head and uncinate process of the pancreas can be exposed with an extended Kocher maneuver. The hepatic flexure of the colon is mobilized and retracted medially and

inferiorly. The second and third portion of the duodenum comes into view and the peritoneum over the lateral wall of the duodenum is incised. Using blunt dissection, the second and third part of the duodenum and the head of the pancreas are mobilized en bloc from their retroperitoneal position and rotated to the left. This exposure allows inspection and palpation of the anterior and posterior surfaces of the head and uncinate process.

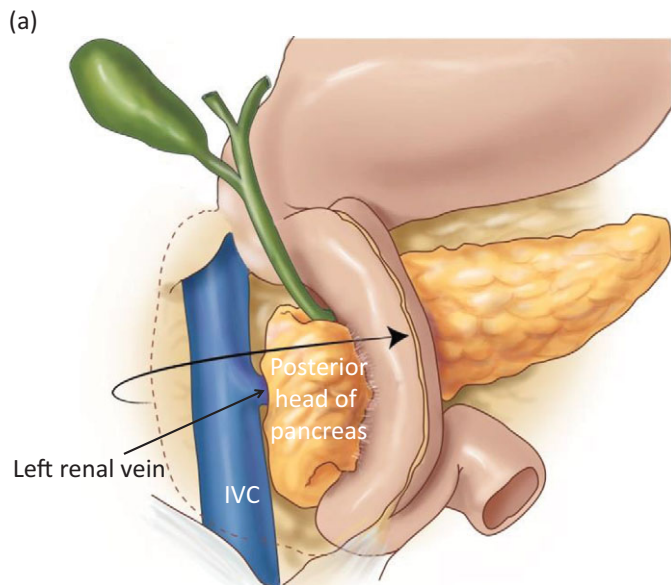
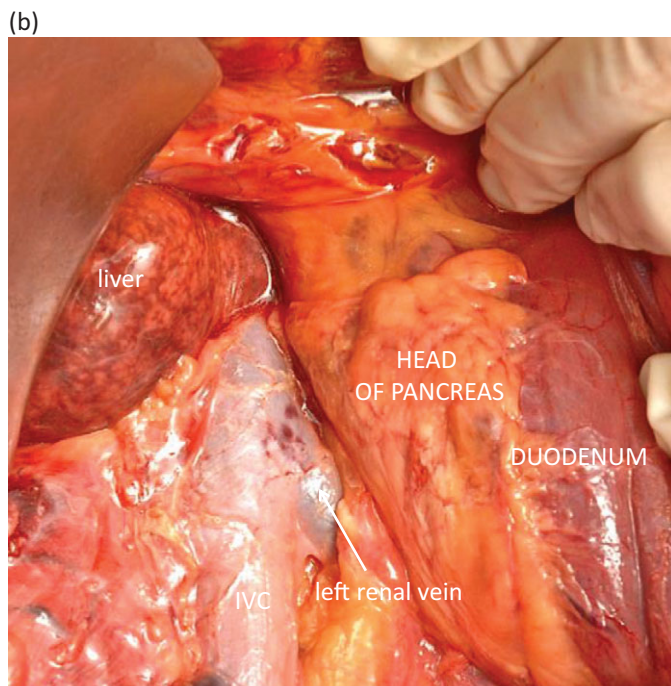
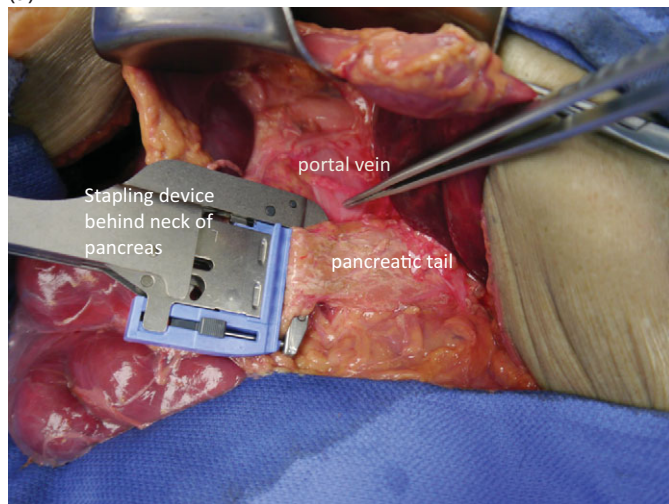


Figure 29.5 (a) Kocher maneuver. The posterior aspect of the head of the pancreas is exposed after medial rotation of the second portion of the duodenum. The IVC and left renal vein are directly under the head of the pancreas.



- In penetrating injuries, associated vascular injuries to the superior mesenteric vessels or the portal vein, under the neck of the pancreas, are common and hemostasis is difficult. In these cases, division of the neck of the pancreas with a stapling device may achieve adequate exposure of the vessels. This can be done by dissecting the avascular plane between the posterior surface of the neck of the pancreas and the portal vein and the superior mesenteric vessels, creating a tunnel to pass the stapler. Care should be taken to stay in the avascular midline to avoid bleeding.

(a)



(b)

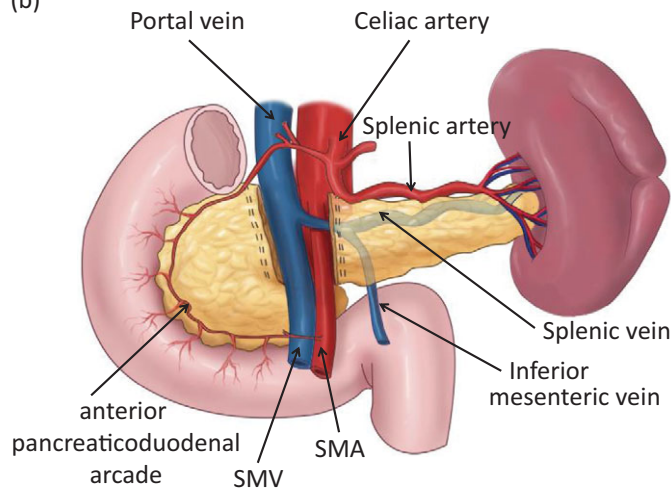


Figure 29.6 (a) Exposure of the superior mesenteric vessels and the portal vein. Division of the neck of the pancreas with a stapling device. The stapling device should be placed in the avascular plane between the posterior surface of the neck of the pancreas and the portal vein and the superior mesenteric vessels. (b) Exposure of the superior mesenteric vessels and the portal vein after division of the neck of the pancreas with a stapling device.

- All peripancreatic hematomas should be explored to evaluate the integrity of the pancreatic duct. However, in some cases with isolated nondestructive injury to the the head of the pancreas, a stable hematoma may be left undisturbed, because the duct in this area is deep in the parenchyma and difficult to explore. These patients should be evaluated postoperatively using MRCP or ERCP. In cases with partial ductal injury, an ERCP-placed stent should be considered as definitive management.
- Normal size pancreatic ducts may be difficult to visualize. The use of magnifying glasses and administration of secretin may facilitate visualization of smaller ductal injuries.
- Radiological and endoscopic methods of intraoperative pancreatography are rarely used in trauma.

Management of Pancreatic Injuries

- Low-grade injuries without ductal injury are best managed with conservative debridement of nonviable tissue, hemostasis, and external drainage with closed suction drains. Repair of the pancreatic capsule may be done, although it is controversial because of concerns about increased risk of pseudocyst formation. Diffuse bleeding may be managed with application of topical hemostatics and tissue glue.
- High-grade injuries with ductal involvement or associated severe duodenal injuries require more complex procedures. The choice of procedure depends on the hemodynamic condition of the patient, the site of the pancreatic injury (head and neck versus tail of the pancreas), and experience of the surgeon.
- Pancreatic injuries to the left of the superior mesenteric vessels are best treated by distal pancreatectomy, often en bloc with the spleen. The first step is to mobilize the body or tail of the pancreas, starting at the point of the injury. The peritoneum at the inferior border of the pancreas is incised and the plane behind the pancreas is developed using blunt dissection, taking care to avoid injury to the splenic vessels, which are near the superior border and behind the pancreas. A vessel loop is then placed around the pancreas.

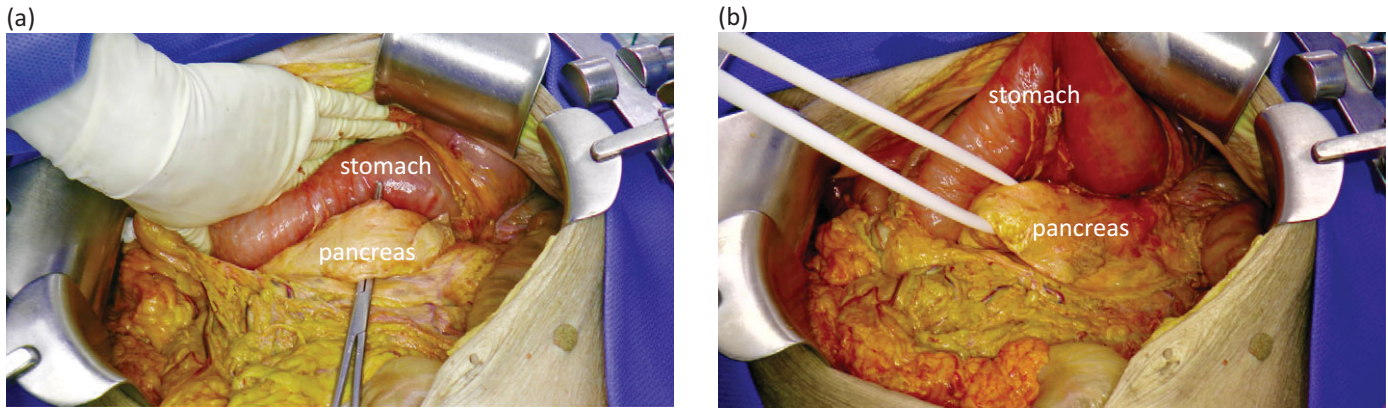


Figure 29.7 (a) Technique of distal pancreatectomy. Mobilization of the tail of the pancreas with caution to avoid injury to the splenic vessels. (b) Mobilization of the tail of the pancreas.

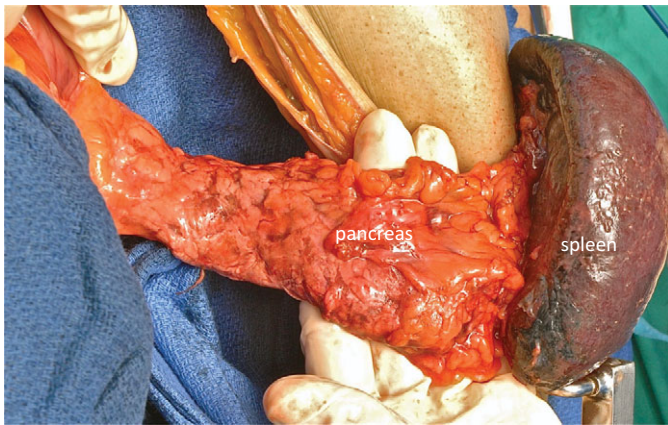


Figure 29.8 Mobilization of the pancreatic tail and the spleen.

The resection of the pancreas is performed just proximal to the injury, through healthy tissues, using a GIA or TA stapling device. If the proximal end of the pancreatic duct is visible it should be suture-ligated with figure-of-eight nonabsorbable sutures. The splenic artery and vein are then individually suture-ligated with figure-of-eight sutures. The pancreatectomy is completed by mobilizing the pancreas distally, towards the spleen. After the dissection reaches the hilum of the spleen, the spleen is mobilized by dividing the vascular gastrosplenic ligament first, followed by division of the splenocolic, splenorenal, and splenodiaphragmatic ligaments (see [Chapter 28 Splenic Injuries](#)). An alternative approach for distal pancreatectomy is to start with mobilization of the spleen, en bloc medial rotation of the spleen with the tail of the pancreas, and a stapled resection proximal to the site of injury.

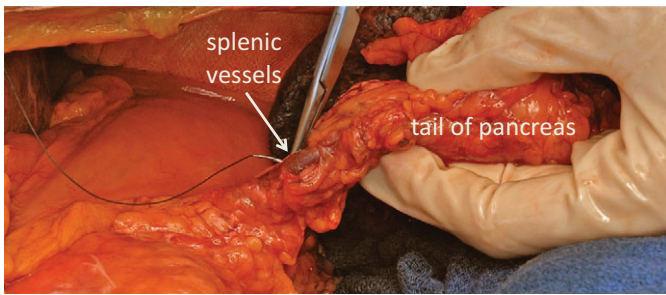


Figure 29.9 Technique of distal pancreatectomy. After mobilization of the tail, the splenic artery and vein are individually suture-ligated.

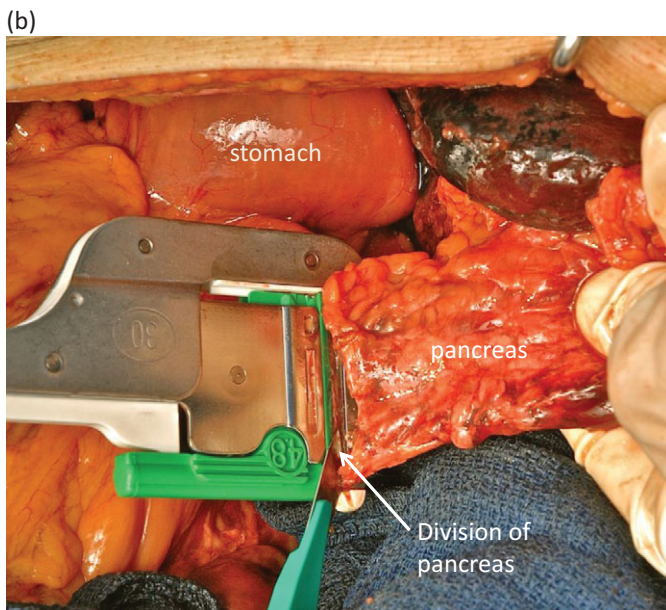
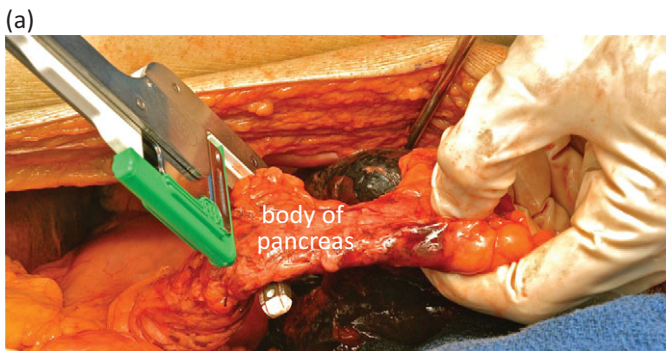


Figure 29.10 (a, b) Placement of TA stapling device and division of the body of the pancreas.

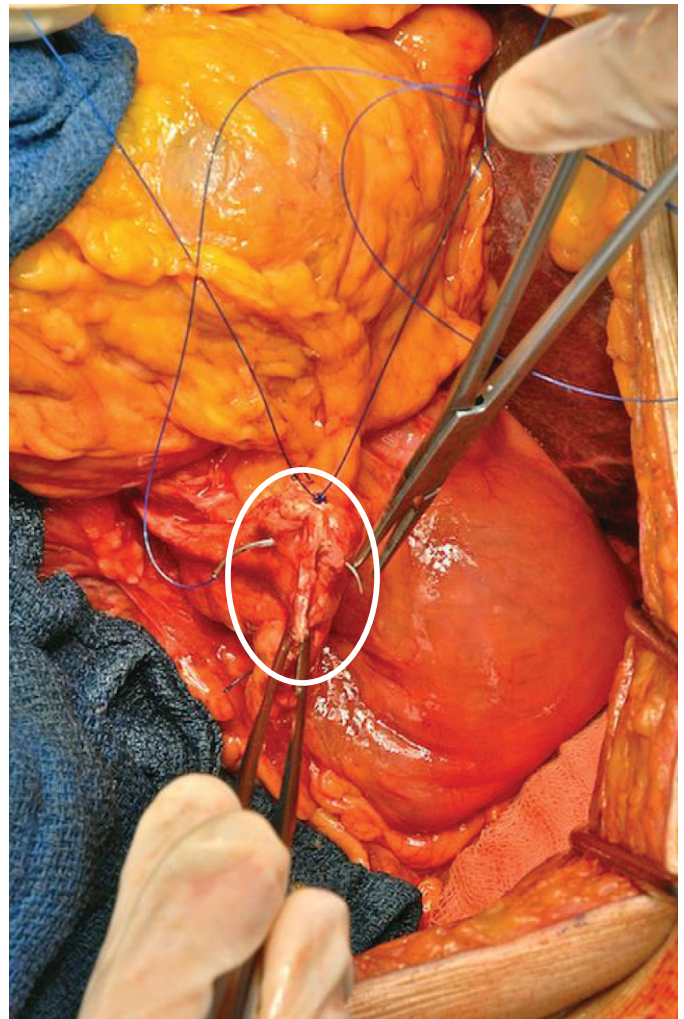


Figure 29.11 The pancreatic stump is oversewn (circle) with nonabsorbable sutures.

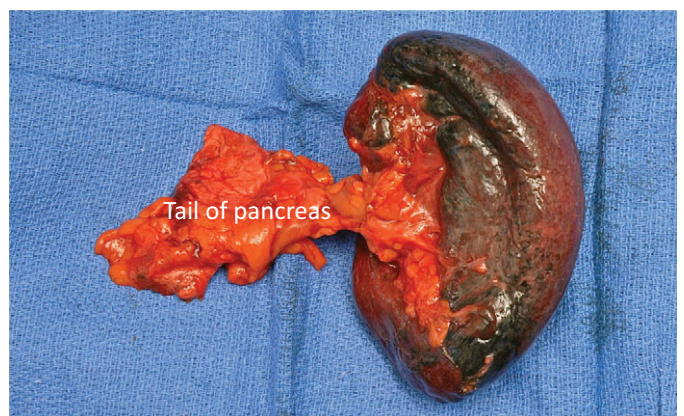


Figure 29.12 En bloc distal pancreatectomy and splenectomy.

- Distal pancreatectomy with splenic preservation may be considered in selected hemodynamically stable patients. The peritoneum is incised at the inferior border of the pancreas, near the area of the injury, and the surgeon dissects the plane behind the pancreas with the index finger or a right-angle forceps. A vessel loop is applied around the pancreas and the splenic artery and vein are dissected free, taking care to clip or ligate and divide the numerous small branches to the pancreatic parenchyma. When the dissection reaches the splenic hilum, the pancreas is removed.
- Pancreatic resection extending to the right of the neck often leads to diabetes and exocrine insufficiency. Preservation of at least 1 cm of pancreatic tissue from the duodenal wall is important in order to maintain the blood supply to the duodenum and avoid ischemic necrosis. In these cases, after debridement of any damaged tissue, the distal pancreas may be preserved and anastomosed to a Roux-en-Y jejunal loop, using an end-to-end pancreaticojejunostomy. Closed suction drains should be always be placed.

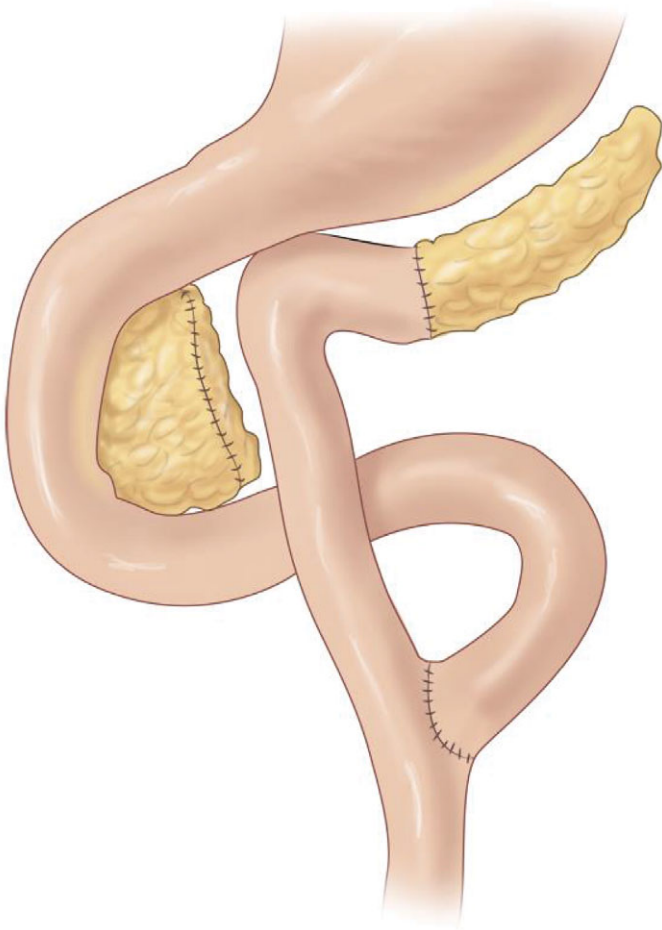


Figure 29.13 Oversewn proximal pancreatic stump and distal Roux-en-Y end-to-end pancreaticojejunostomy.

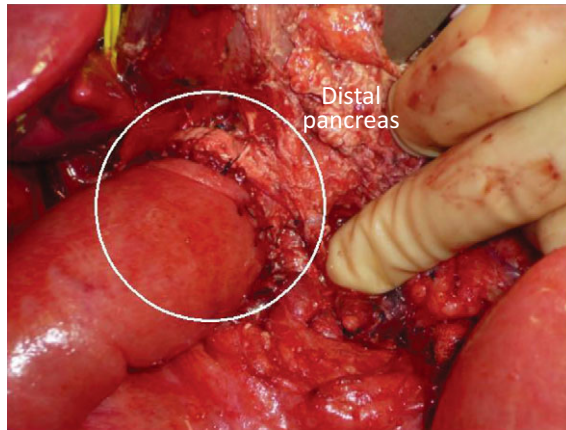


Figure 29.14 Completed end-to-end pancreaticojejunostomy, with invagination and suturing of the pancreatic stump into the jejunum.

- Injuries to the head of the pancreas may require complex operations associated with high mortality and morbidity. In the presence of hemodynamic instability or major associated injuries, or if the surgeon has no experience with these injuries, the safest option is hemostasis and damage control with packing and temporary abdominal closure, followed by semielective definitive management.
- In destructive injuries to the head of the pancreas or the duodenum, a pancreaticoduodenectomy may be necessary. It should only be performed as a primary procedure in hemodynamically stable patients by an experienced surgeon. In coagulopathic or physiologically compromised patients, the surgeon should opt for damage control and a two-stage procedure. At the initial operation, damage control surgery should be performed to control the hemorrhage and any intestinal spillage. The definitive Whipple's pancreaticoduodenectomy should be deferred for 24–36 hours, after restoration of hemodynamic stability, and correction of any coagulopathy and hypothermia. The reconstruction, including pancreaticojejunostomy, choledochojejunostomy, and gastro-enterostomy, is similar to that in elective cases and will not be discussed in the current atlas.
- Insertion of a jejunal feeding tube beyond the ligament of Treitz is recommended in cases undergoing pancreaticoduodenectomy or complex duodenal repairs, in order to allow enteral nutrition in cases with postoperative anastomotic leaks.

Tips and Pitfalls

- Pancreatic injuries without ductal involvement rarely cause significant problems and do not require operation.
- Distal pancreatectomy (to the left of the neck of the pancreas) rarely results in permanent diabetes or pancreatic exocrine insufficiency.

- Mobilization and separation of the head of the pancreas from the medial aspect of the duodenal loop results in duodenal ischemia and necrosis. A minimum of 1 cm of pancreatic tissue should be left behind in order to preserve the pancreaticoduodenal vascular arcades.
- In isolated injuries involving the head of the pancreas, if the integrity of the duct cannot be confirmed, pancreatic drainage alone should be considered. Radical resections should be avoided because of the high mortality and morbidity. The pancreatic duct should be evaluated postoperatively by means of MRCP or ERCP. In selected cases with ductal injury, ERCP-placed stenting may be considered.
- During tunnelling between the neck of the pancreas and the superior mesenteric vessels and portal vein, stay in the midline, directly under the neck. This area is avascular.

Urological Trauma

Leo R. Doumanian, Charles D. Best, Jessica A. Keeley, and Stephen Varga

Surgical Anatomy

Kidney

- Both kidneys have similar muscular surroundings. Posteriorly, the diaphragm covers the upper third of each kidney. Medially, the lower two-thirds of the kidney lie against the psoas muscle, and laterally, the quadratus lumborum.
- The right kidney borders the duodenum medially. Its lower pole lies behind the hepatic flexure of the colon.
- The left kidney is bordered superiorly by the tail of the pancreas, the spleen superolaterally, and the splenic flexure of the colon inferiorly.
- The Gerota's fascia encloses the kidney and is an effective barrier for containing blood or a urine leak.
- The renal artery and vein travel from the aorta and IVC just below the SMA at the level of the second lumbar

vertebra. The vein lies anterior to the artery. The renal pelvis and ureter are located posterior to the vessels.

- The right renal artery takes off from the aorta with a downward slope under the IVC into the right kidney. The left renal artery courses directly off the aorta into the left kidney. Each renal artery branches into five segmental arteries as it approaches the kidney.
- The right renal vein is typically 2–4 cm in length, does not receive any branches, and enters into the lateral edge of the IVC. Ligation of the vein causes hemorrhagic infarction of the kidney because of the lack of collaterals.
- The left renal vein is typically 6–10 cm in length, passes posterior to the SMA and anterior to the aorta. The left renal vein receives branches from the left adrenal vein superiorly, lumbar veins posteriorly, and the left gonadal vein inferiorly. This allows for ligation of the left renal vein close to the IVC.

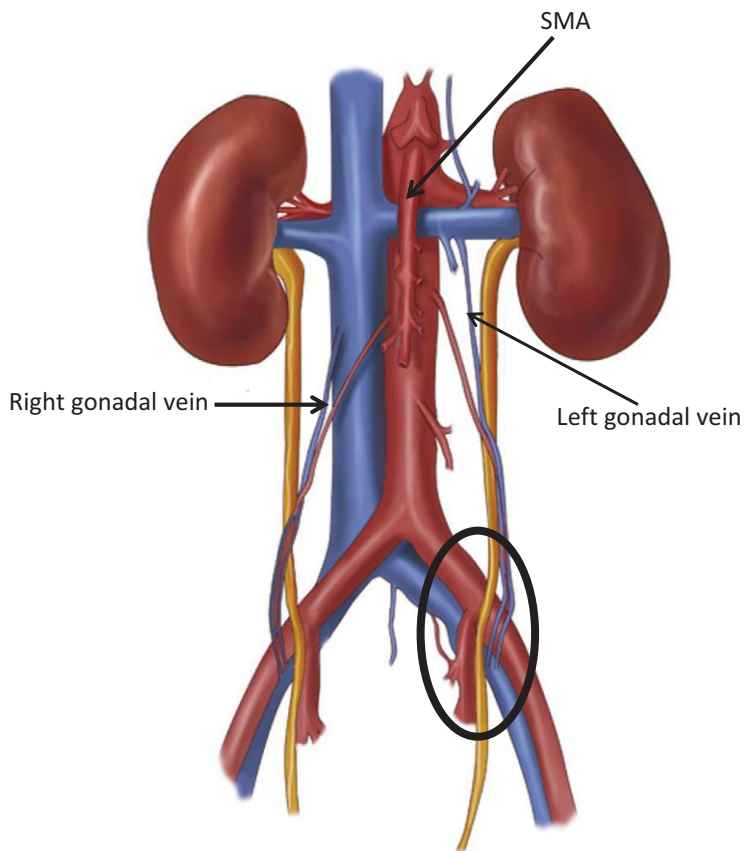


Figure 30.1 Anatomy of the kidneys and ureters and their relationship with the major vessels. Note the right renal artery coursing under the inferior vena cava. Also, note the different drainages of the right and left gonadal veins. The ureters cross over the bifurcation of the common iliac arteries (circle). SMA, superior mesenteric artery.

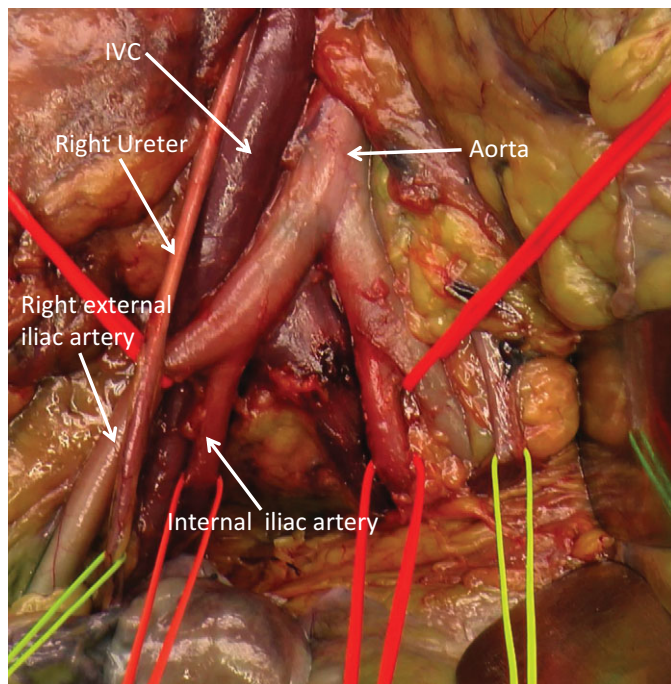


Figure 30.2 The distal ureter crosses over the bifurcation of the common iliac artery.

Ureter

- The ureter courses posterior to the renal artery and travels along the anterior edge of the psoas muscle.
- The gonadal vessels cross anterior to the ureter.
- It crosses over the bifurcation of the common iliac artery.

Bladder

- The superior surface of the bladder is covered by the peritoneum. Posteriorly, the peritoneum passes to the level of the seminal vesicles (in males) and meets the peritoneum on the anterior rectum.
- The bladder neck rests approximately 3–4 cm behind the midpoint of the symphysis pubis.
- The bladder neck and ureteral orifices form a triangular structure known as the bladder plate or trigone. The ureteral orifices are located at the right and left apex of the trigone. The ureteral orifices are in close proximity to the bladder neck.

Kidney Injuries

General Principles

- In hemodynamically stable patients, the vast majority of blunt and a significant proportion of penetrating renal injuries can be managed nonoperatively. Gerota's fascia effectively contains bleeding and urine leaks. CT scan evaluation is important in assessing the severity and location of the injury. Delayed CT scan allows the evaluation of the collecting system and proximal ureter.
- If no preoperative imaging is available and the patient is undergoing exploratory laparotomy, it is important to assess by palpation the presence and size of the contralateral kidney.
- Intraoperatively, in a hemodynamically stable patient, in the absence of active bleeding or expanding hematoma or injury to the hilar vessels, Gerota's fascia should not be opened, as it increases the probability of nephrectomy.
- Nephrectomy should be reserved for life-threatening hemorrhage or renal injuries that are beyond repair, approximately in 10% of renal injuries.
- If time allows, proximal vascular pedicle control should be considered before kidney exploration in order to reduce the need for nephrectomy.

Patient Positioning

- The patient is placed in the standard trauma laparotomy position, supine with both arms abducted at 90° to allow access to the extremities.

Incision

- Standard midline trauma laparotomy incision. A Bookwalter or other fixed abdominal retractor facilitates the exposure.

Kidney Exposure

- Proximal vascular control, before opening the Gerota's fascia, may be considered in stable patients if a kidney-preserving operation is planned. This approach increases the chances of kidney salvage.
- In unstable patients or those undergoing a planned nephrectomy, a direct approach through Gerota's fascia without prior vascular control is faster and preferable.

Proximal Renal Vascular Control

- Proximal control of both the left and right renal vessels can be obtained directly through a single incision of the retroperitoneum over the abdominal aorta.
 - The transverse colon is retracted anteriorly and superiorly towards the patient's chest. The small intestine is wrapped in a moist towel and retracted superiorly and to the right to expose the ligament of Treitz, the root of the mesentery, and the underlying great vessels.
 - An incision is made in the posterior peritoneum, over the aorta, just above the inferior mesenteric vein. The dissection continues superiorly along the aorta until the left renal vein is identified crossing over anteriorly. A vessel loop is placed around the vein for retraction. Once the left renal vein is mobilized and retracted, dissect out the left renal artery, which is located posterior to the renal vein.

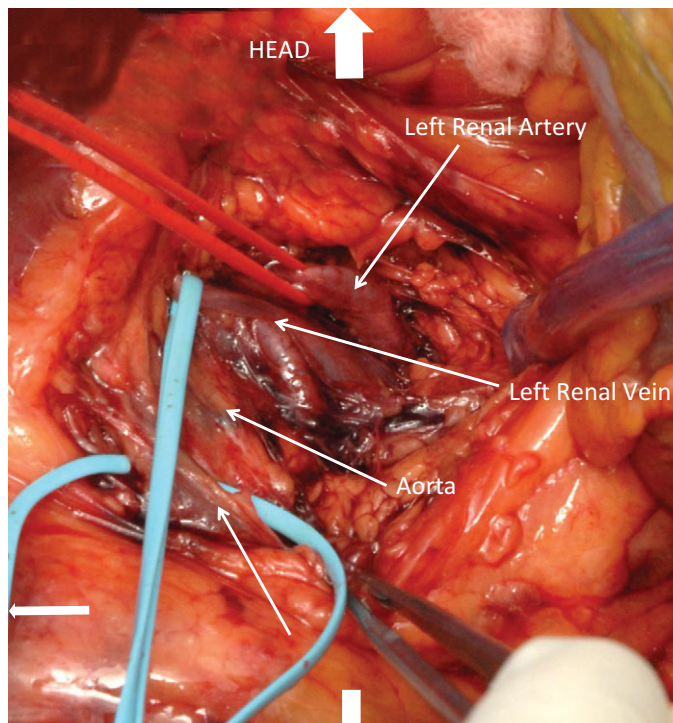


Figure 30.3 Dissection in the posterior peritoneum lateral to the aorta and just above the inferior mesenteric vein and continuing superiorly along the aorta will identify the left renal vein crossing the aorta anteriorly. The left renal artery is located posterior to the vein.

- After vascular control has been achieved, a medial visceral rotation is performed by mobilizing the left colon along the white line of Toldt and reflecting the colon medially. The kidney is then exposed by making an anterior vertical incision in Gerota's fascia.

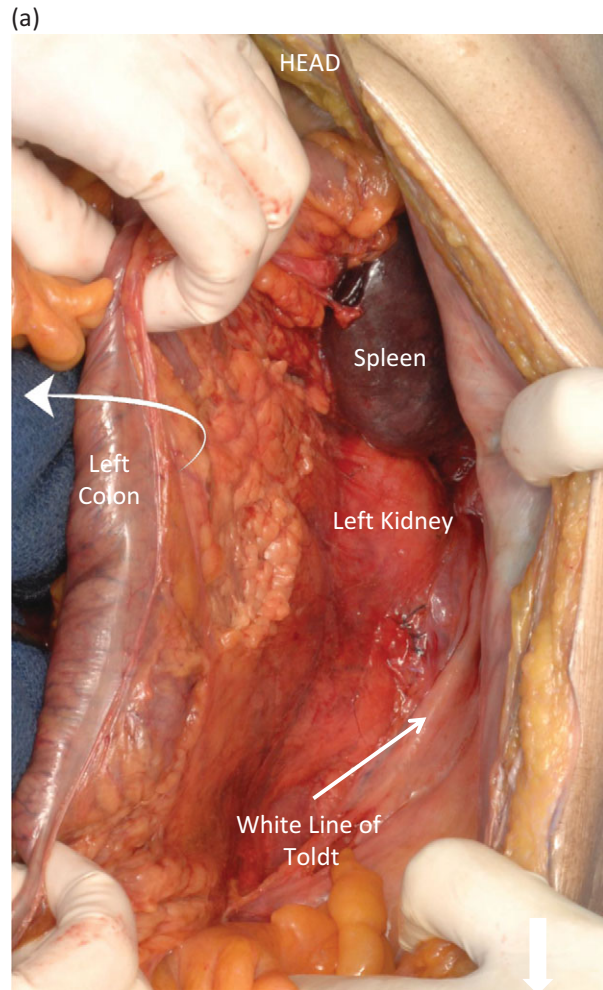
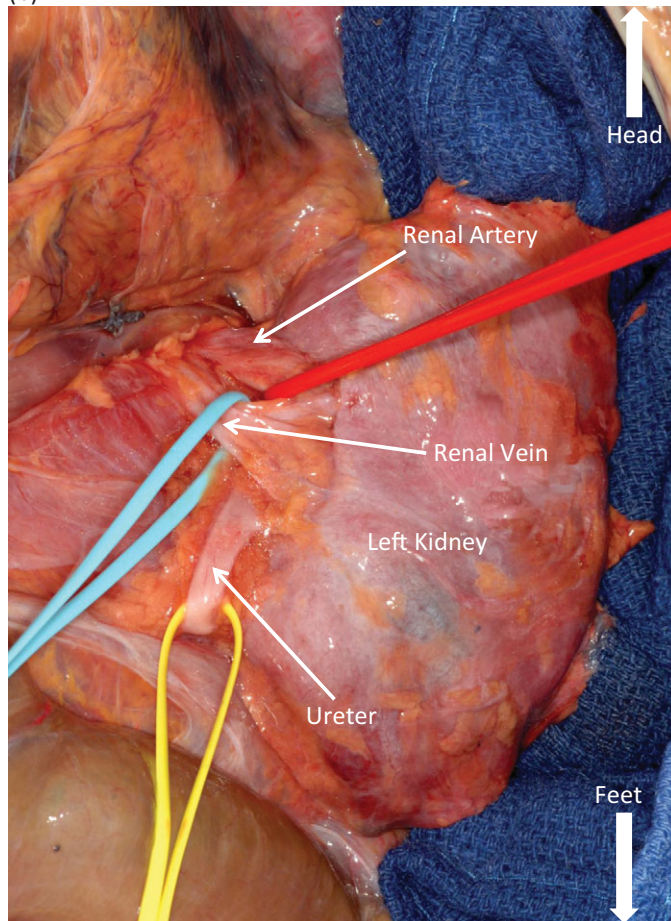
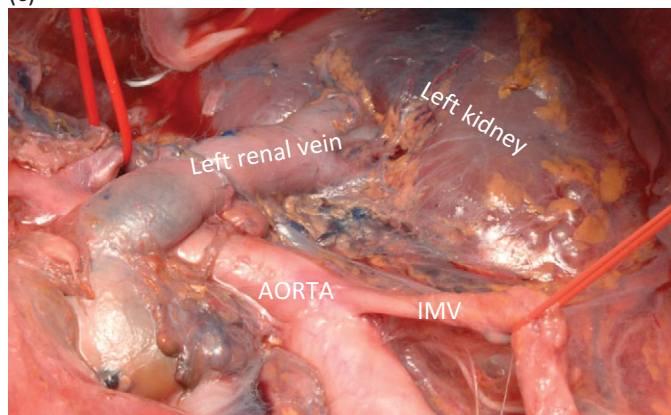


Figure 30.4 (a) Incision of the white line of Toldt and mobilization and medial rotation of the left colon exposes the left kidney. **(b)** Exposure of the left kidney and the hilum after medial rotation of the left colon (artery in red, vein in blue, and ureter in yellow loop). **(c)** Exposure of the left kidney and the hilum after medial rotation of the left colon. Note the left renal vein crossing over the aorta. IMV, inferior mesenteric vein; IVC, inferior vena cava.

(b)



(c)

**Figure 30.4** (cont.)

- The right renal vessels can be exposed through the same posterior peritoneal incision described above. The right renal artery originates from the right side of the aorta and courses under the inferior vena cava and behind the renal vein.
- As described above, the left renal vein is mobilized and retracted as it crosses over the aorta. The right renal artery, which is located posterior to the vein and to the right of the aorta, is identified.
- Finally, identify the right renal vein traveling to the inferior vena cava and control with a vessel loop.
- After vascular control has been achieved, perform a right medial visceral rotation, mobilizing the right colon by incising the white line of Toldt and reflecting it medially.
- Explore the right kidney by making an anterior vertical incision in Gerota's fascia. Completely expose the kidney, mobilizing it and lifting it anteriorly into the wound.

(a)

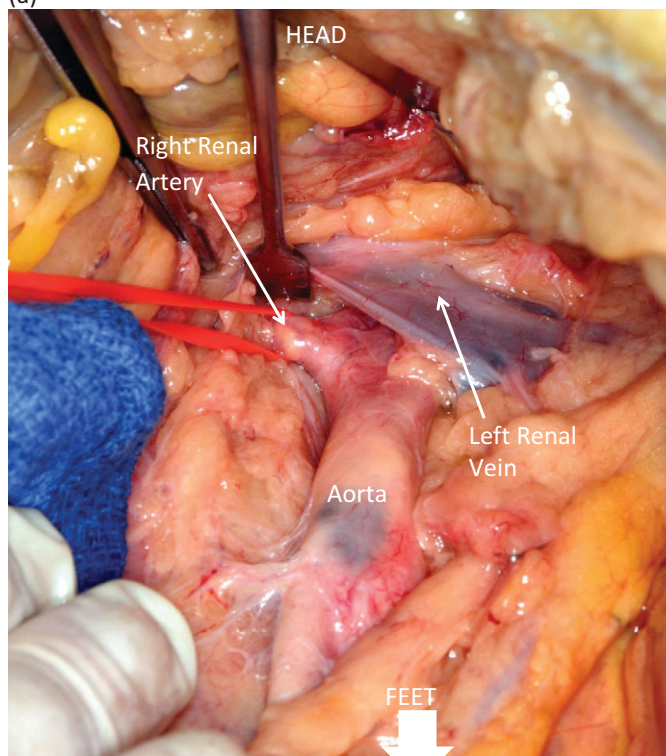


Figure 30.5 (a) Exposure of the right renal vessels through a midline retroperitoneal dissection. The left renal vein is identified as it crosses over the aorta and is retracted to expose the underlying right renal artery (red loop). (b) Exposure of the right kidney and the hilum after medial rotation of the right colon. Note the renal vein anteriorly, the artery posteriorly, and the ureter inferiorly.

(b)

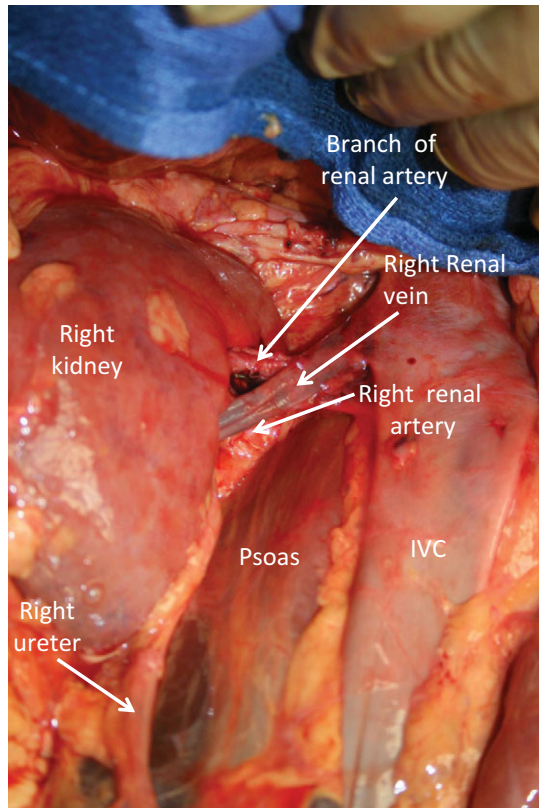


Figure 30.5 (cont.)

Direct Kidney Exposure without Prior Vascular Control

- This is a common approach to the kidney and the preferred approach in patients with hemodynamic instability or unsalvageable renal injuries.
- A medial visceral rotation is performed by mobilizing the left or right colon after incising the white line of Toldt.
- Gerota's fascia is opened with an anterior vertical incision and the kidney is exposed and delivered anteriorly.
- The blood supply and ureter can then be controlled.

Renal Injury Repair

- After opening Gerota's fascia and exposing the kidney, the extent of the injury is assessed. In cases with significant bleeding from the parenchyma, the renal vessels are clamped for bleeding control. Manual compression of the bleeding parenchyma is often adequate for temporary control of the hemorrhage. Any significant bleeders are controlled by suture ligation or electrocautery.
- Once hemorrhage is controlled, any devitalized tissue is sharply excised. The collecting system is carefully examined and any injury is repaired watertight with 4-0 absorbable suture.

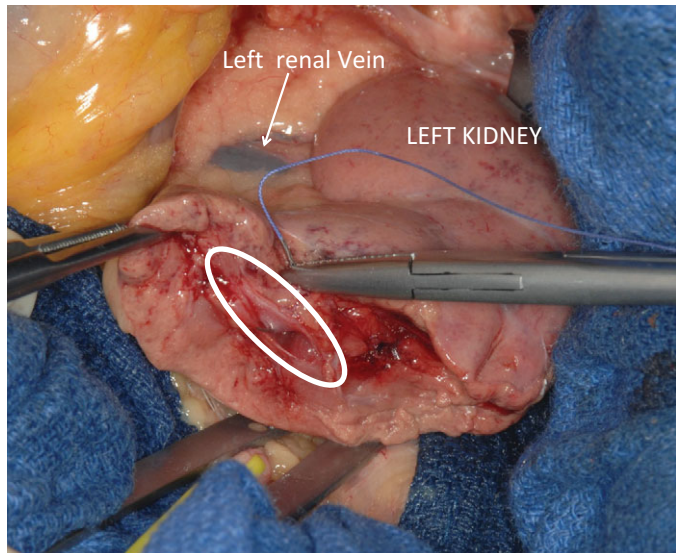


Figure 30.6 Repair of injury to the collecting system (circle), of the lower pole of the left kidney, with 4-0 absorbable suture.

- If unsure of the presence of a collecting system injury or to check if the collecting system repair is watertight, methylene blue can be used to look for a leak. Place a bulldog clamp on the proximal ureter and, using a 22-gauge or smaller butterfly needle, directly inject 2–3 mL methylene blue into the renal pelvis to look for further leaks or injury. If identified, close the leaks or repair the injury with figure-of-eight, 4-0 absorbable sutures.

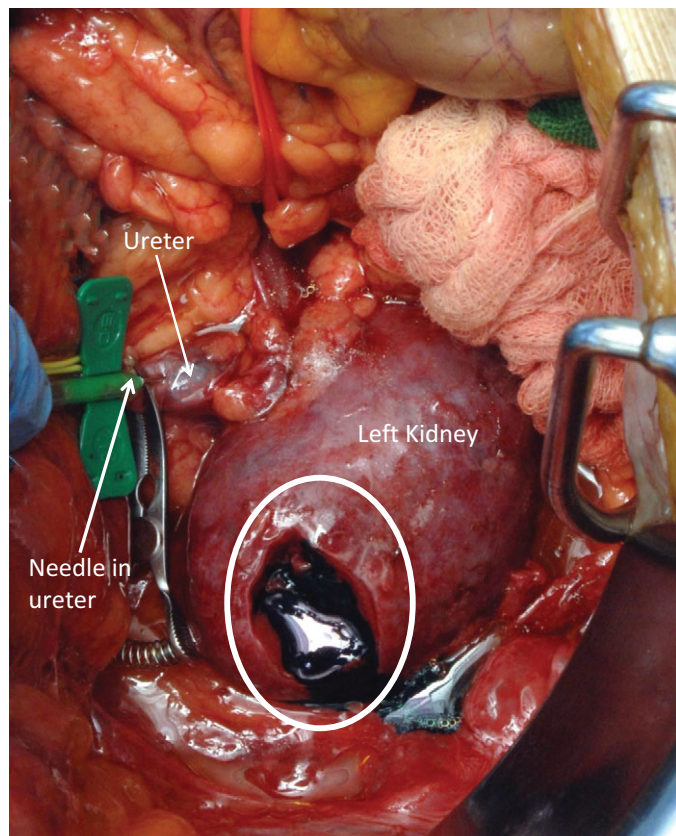


Figure 30.7 Intraoperative evaluation of the integrity of the collecting system. Insertion of a 22-gauge needle into the proximal ureter, with bulldog clamp applied distally, and injection of 2–3 mL of methylene blue into the renal pelvis. Extravasation of the methylene blue (circle) confirms injury to the collective system.

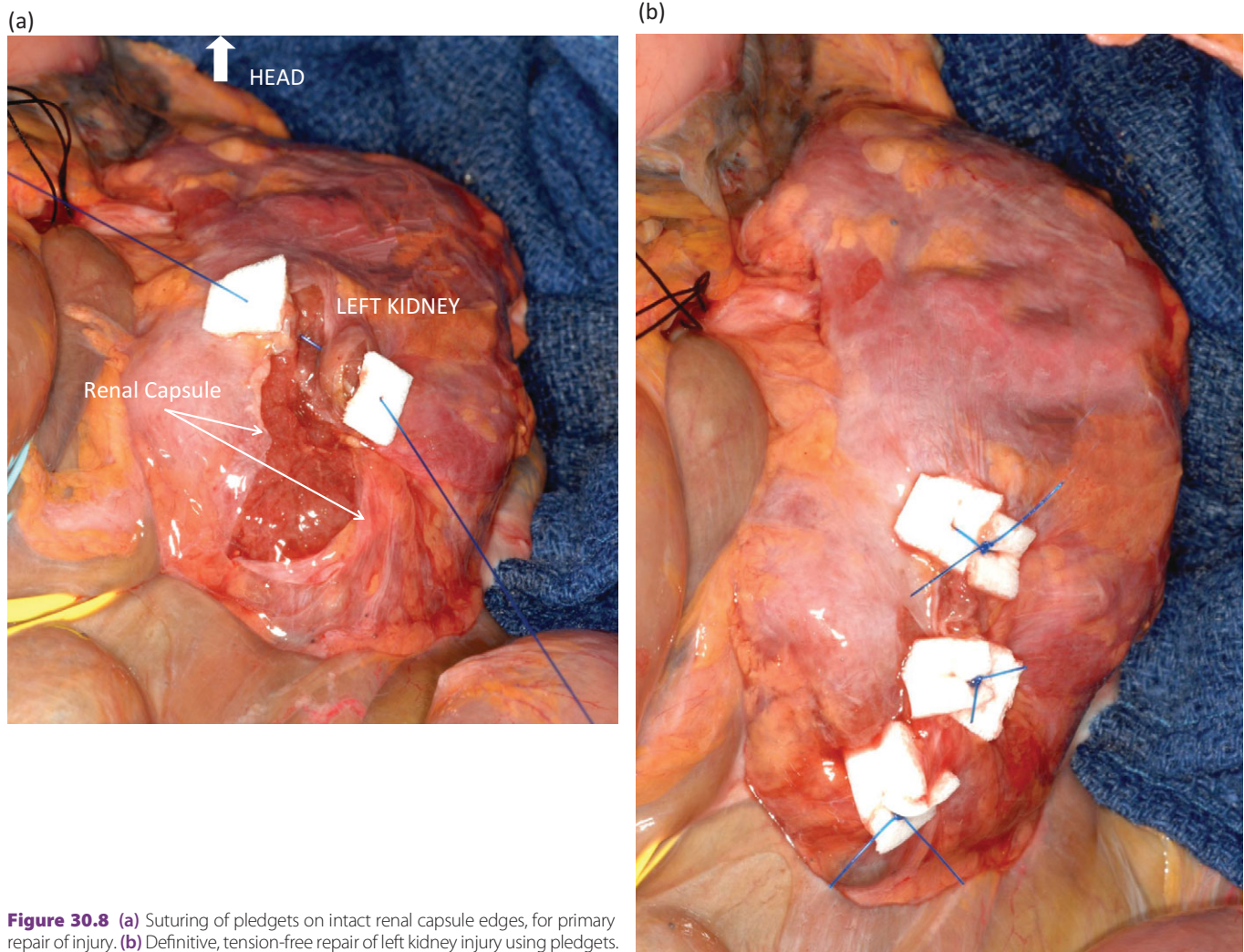


Figure 30.8 (a) Suturing of pledgets on intact renal capsule edges, for primary repair of injury. (b) Definitive, tension-free repair of left kidney injury using pledgets.

- If possible, the renal capsule should be primarily closed without tension, using pledgets.
- If the defect in the capsule is large, an omental pedicle flap, fibrin sealant, or thrombin-soaked Gelfoam bolsters can be used to fill the defect. The capsule should then be closed over the bolster or flap with pledgeted 4-0 polypropylene sutures.

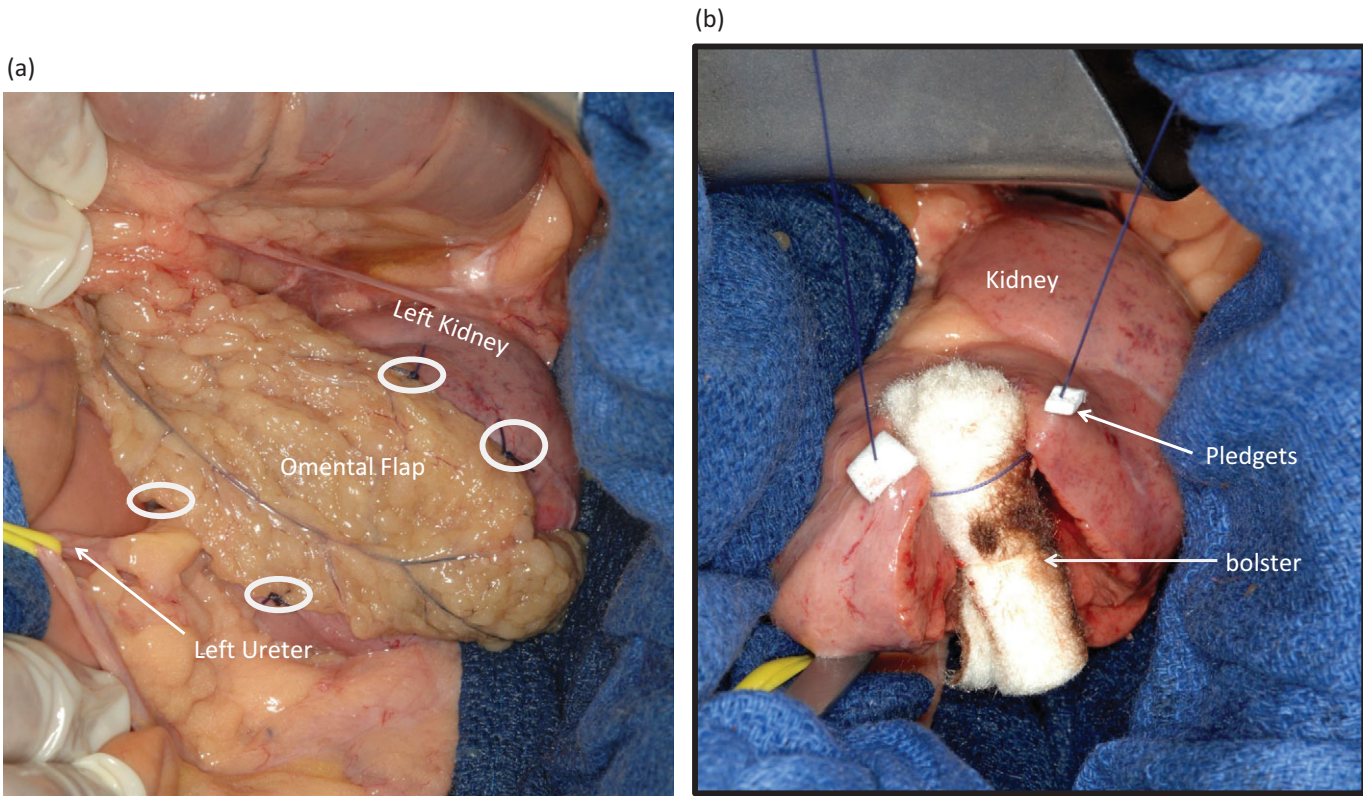


Figure 30.9 (a) Omental pedicle flap may be used to fill in large parenchymal defects, not amenable to primary repair. The flap is anchored to the capsule with sutures (circles). (b) Hemostatic bolster used to repair a large defect that cannot be closed primarily without tension, with closure of the capsule over the bolster.

- If other intra-abdominal injuries are present, an omental interposition flap should be placed over the renal injury to separate the kidney from the other injuries.
- A retroperitoneal drain should be placed at the end of the operation.

Partial Nephrectomy

- Extensive damage to the upper or lower poles of the kidney requires partial nephrectomy rather than primary repair. First, attempt to dissect the capsule off of the damaged parenchyma for assistance with closure later.
- Perform a guillotine transection of the renal parenchyma back to healthy bleeding tissue. Control

small bleeding vessels with figure-of-eight 4-0 absorbable sutures, and close the collecting system in a watertight fashion with 4-0 absorbable suture. Topical hemostatics may be placed on the renal parenchyma to aid in hemostasis.

- If the renal capsule has been preserved, close the capsule over the raw surface of the kidney with 3-0 polypropylene or vicryl suture, with or without pledgets. If the capsule could not be preserved or the injury is too extensive to cover completely, the defect can be covered by an omental flap or absorbable material such as Gelfoam, which can be sutured to the remaining renal capsule with 3-0 polypropylene or vicryl sutures.

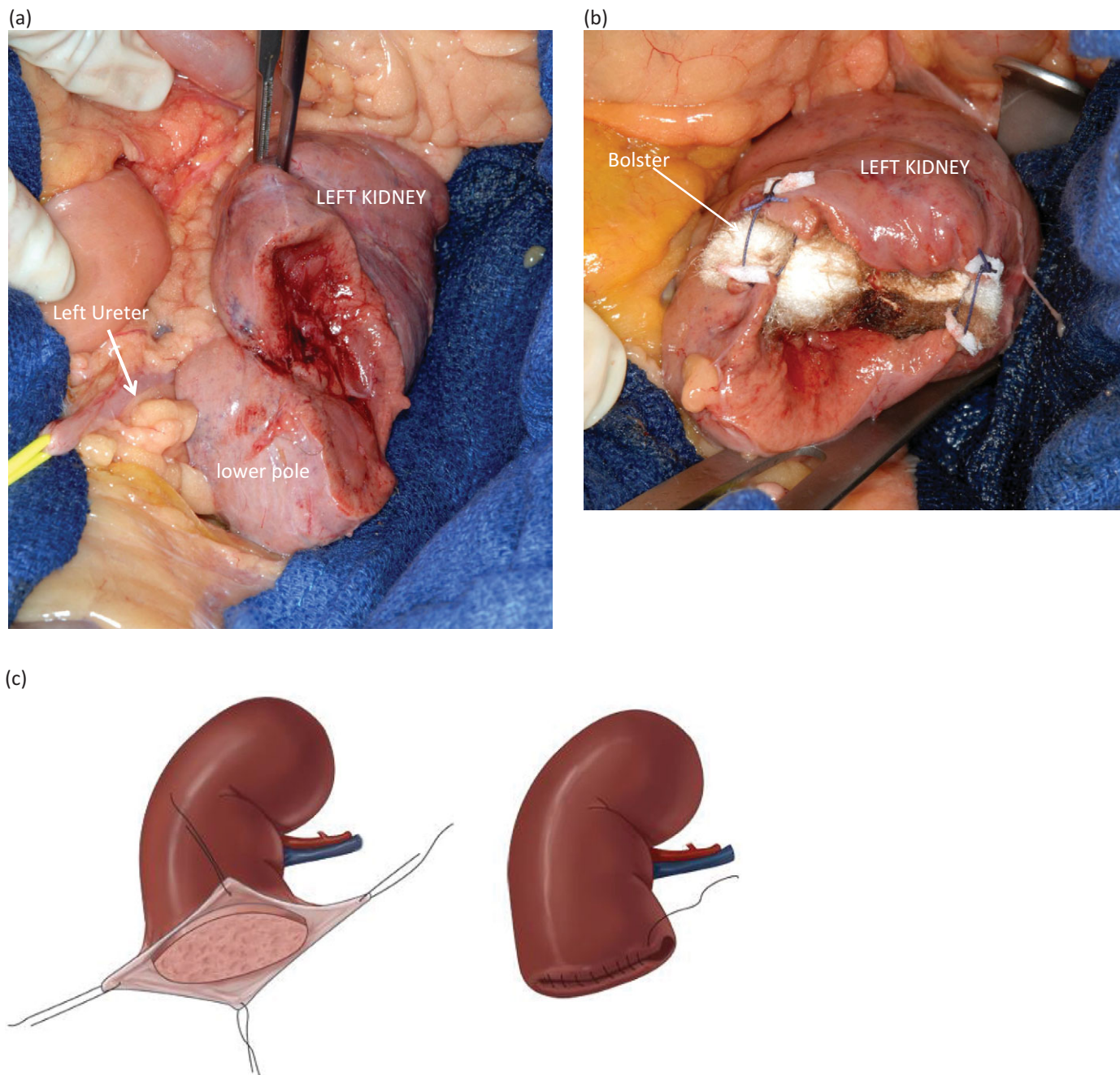


Figure 30.10 (a) Extensive damage to the lower poles of the kidney is best managed with partial nephrectomy. (b) Partial lower pole nephrectomy with the raw surface covered with absorbable materials such as Gelfoam, which can be sutured to the remaining renal capsule. (c) Partial lower pole nephrectomy with preservation of the capsule. The capsule can be closed over the raw surface of the kidney.

- A retroperitoneal drain should be placed at the end of the operation.

Nephrectomy

- If the injury to the kidney is too extensive for repair, a nephrectomy is warranted. If the patient is unstable, and the kidney is the source of hemorrhage, likewise

nephrectomy is warranted. No preliminary vascular isolation is needed. After medial visceral rotation, Gerota's fascia is opened and the kidney is delivered anteriorly. Digital compression of the hilum is applied to control the bleeding. Ligate the artery and the vein, near the kidney hilum, with 0 silk ties. The ureter should be identified and ligated with a 2-0 silk tie.

Technical Pitfalls

- Failure to identify a collecting system injury or failure to perform a watertight closure of the collecting system may result in a urinoma postoperatively.
- Parenchymal tissue typically will not hold a suture, so capsular tissue approximation should be used.
- During debridement or partial nephrectomy, preserve as much renal capsule as possible for repair or cover of the raw surface.
- Attempting to close the capsule primarily over a large defect will cause tearing of the capsule and further bleeding or injury. Omentum or Gelfoam can be utilized to cover the bare area.
- Postoperative urine leak increases the risk of breakdown of any adjacent hollow viscus or vascular anastomosis or repair. Separate the renal repair from other organ injuries with omentum or other available tissue. Routine closed suction drains should be placed.

Postoperative Care

- Patients who have undergone kidney repair should be followed with periodic urinalysis, blood pressure monitoring, and CT scan with intravenous contrast, in order to rule out early or late complications, such as a urinoma, kidney infarct, false aneurysm, arteriovenous fistula, or secondary hypertension.
- Urinomas are the most common complication, and they can be managed by endoscopic stenting with or without percutaneous drainage.
- False aneurysms or arteriovenous fistulas can be managed by angioembolization.
- Hypertension can be managed medically, but if medical management fails, a delayed nephrectomy may be indicated.

Ureter Injury

General Principles

- Early recognition and treatment of ureteral injuries are important because failure to recognize these injuries can result in serious complications.
- In patients undergoing laparotomy for penetrating trauma, all retroperitoneal hematomas should be explored and the ureter examined for any injury. The ureter can be inspected with or without the use of intravenous or intraureteral dye.
- The ureter can be divided into three separate anatomical areas when considering repair, including the proximal, mid, and distal ureter. The proximal ureter is the segment above the iliac bifurcation. The mid ureter is the segment between the iliac bifurcation and the deep pelvis. The distal ureter is defined as the segment of ureter below the internal iliac artery. Each of these anatomic areas requires a different type of repair.

- The type of ureteral repair depends on the level of the injury, the amount of ureteral loss, and the condition of the patient. The general principles for all ureteral repairs are debridement to healthy tissue, with a tension-free watertight repair over a stent.
- In severe trauma, the patient may not be stable enough to undergo extensive ureteral repair during the initial operation. In these cases, a damage control procedure should be considered. If a ureteral transection is identified, the proximal and distal ends of the ureter can be ligated and tagged and left in place to be repaired semielectively after the patient has stabilized. Alternatively, an external stent can be placed in the proximal ureter and brought out through the abdominal wall through a separate stab incision in the abdomen to allow for monitoring of urine output during resuscitation. Immediate diversion is not necessary, as the affected kidney can tolerate complete obstruction for several days until definitive repair can be performed. If repair will be significantly delayed for clinical reasons, a percutaneous nephrostomy tube should be considered.

Repair of the Proximal and Mid Ureter

- Explore the retroperitoneum by performing a medial visceral rotation, mobilizing the ipsilateral colon by incising the white line of Toldt and reflecting it medially.
- Identify the ureter and trace it proximally and distally to examine the extent of injury. The ureter is mobilized to allow the proximal and distal ends of the injury to be approximated without tension. Care should be taken not to devitalize the ureter during mobilization.
- The injured part of the ureter should be debrided to viable tissue.
- Spatulate the ends of the ureter to prevent stenosis at the suture line.

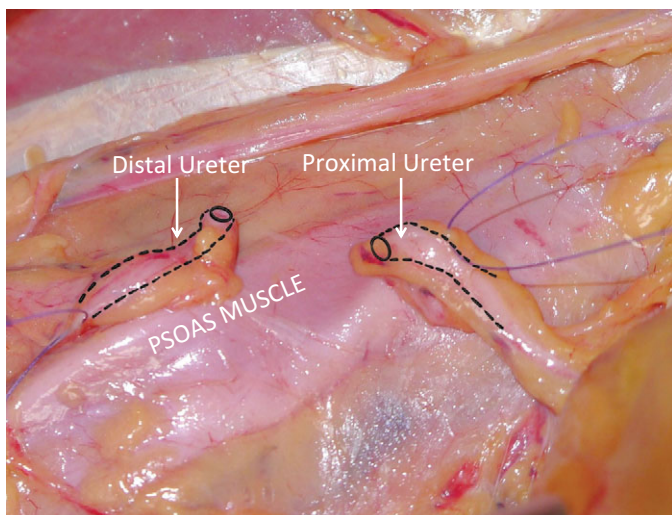


Figure 30.11 Ureter transection sharply debrided to healthy tissue prior to anastomosis.

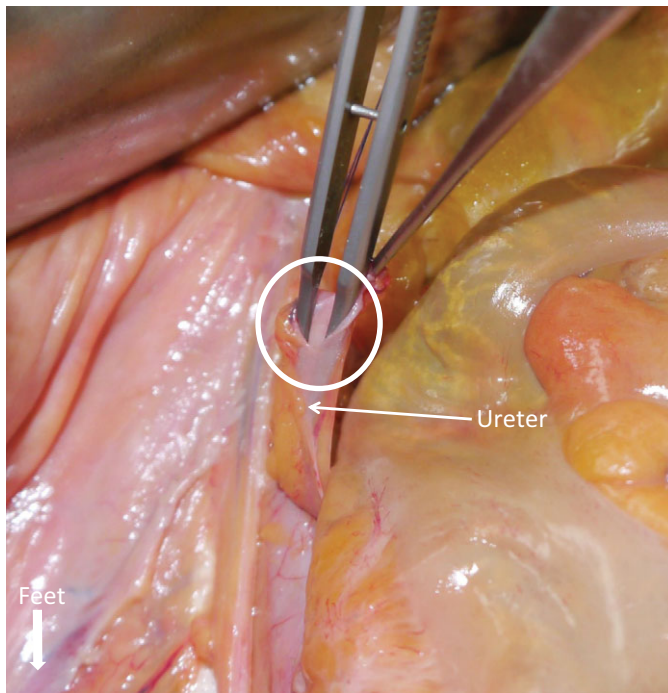


Figure 30.12 Spatulated end (circle) of the transected ureter.

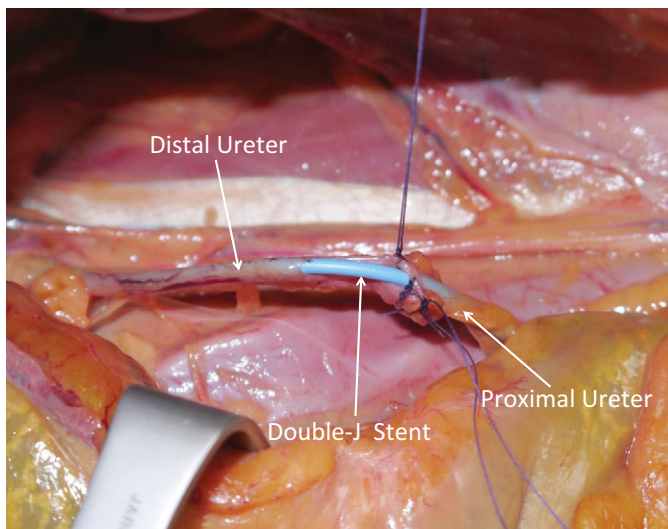


Figure 30.13 Placement of an indwelling double-J-type stent into the proximal and distal ends of the ureter.

- Place an indwelling double-J-type stent into the proximal and distal ends of the ureter.
- Perform a tension-free, mucosa-to-mucosa anastomosis, using interrupted 4-0 or 5-0 absorbable suture. Bolster the repair with mental flap.

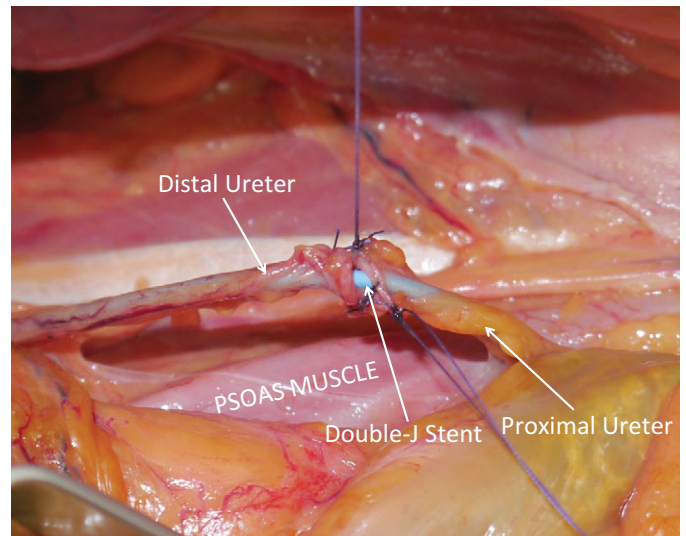


Figure 30.14 Tension-free, mucosa-to-mucosa anastomosis using interrupted 4-0 absorbable sutures over double-J-type stent.

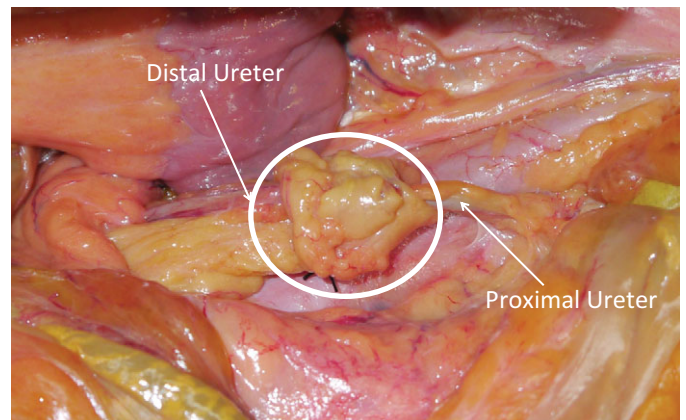


Figure 30.15 Omental flap (in circle) covering ureteral anastomosis.

- Place a retroperitoneal drain near the repair site. In the case of bowel or pancreatic injuries in addition to ureteral injuries, every attempt should be made to isolate the ureteral repair from the other injuries by covering it with an omental flap or local tissue.

Repair of the Distal Ureter

- Distal ureter injuries usually occur in the setting of a pelvic hematoma, making the dissection difficult. If an injury is identified, direct reimplantation of the distal ureter into the bladder is preferable if it can be performed tension-free. This should be done in an anti-refluxing fashion, if possible, over a stent.
- Although anti-refluxing is not crucial in the adult patient, an attempt should be made to perform an anti-refluxing tunnel with an extravesical reimplant, if a psoas hitch is not required. Once the ureter has been adequately mobilized, a tunnel is created in the posterolateral dome by dissecting off the detrusor muscle, leaving small muscle flaps on either side. A hole can be made in the bladder mucosa at the apex of this trough, and the spatulated ureteral end can

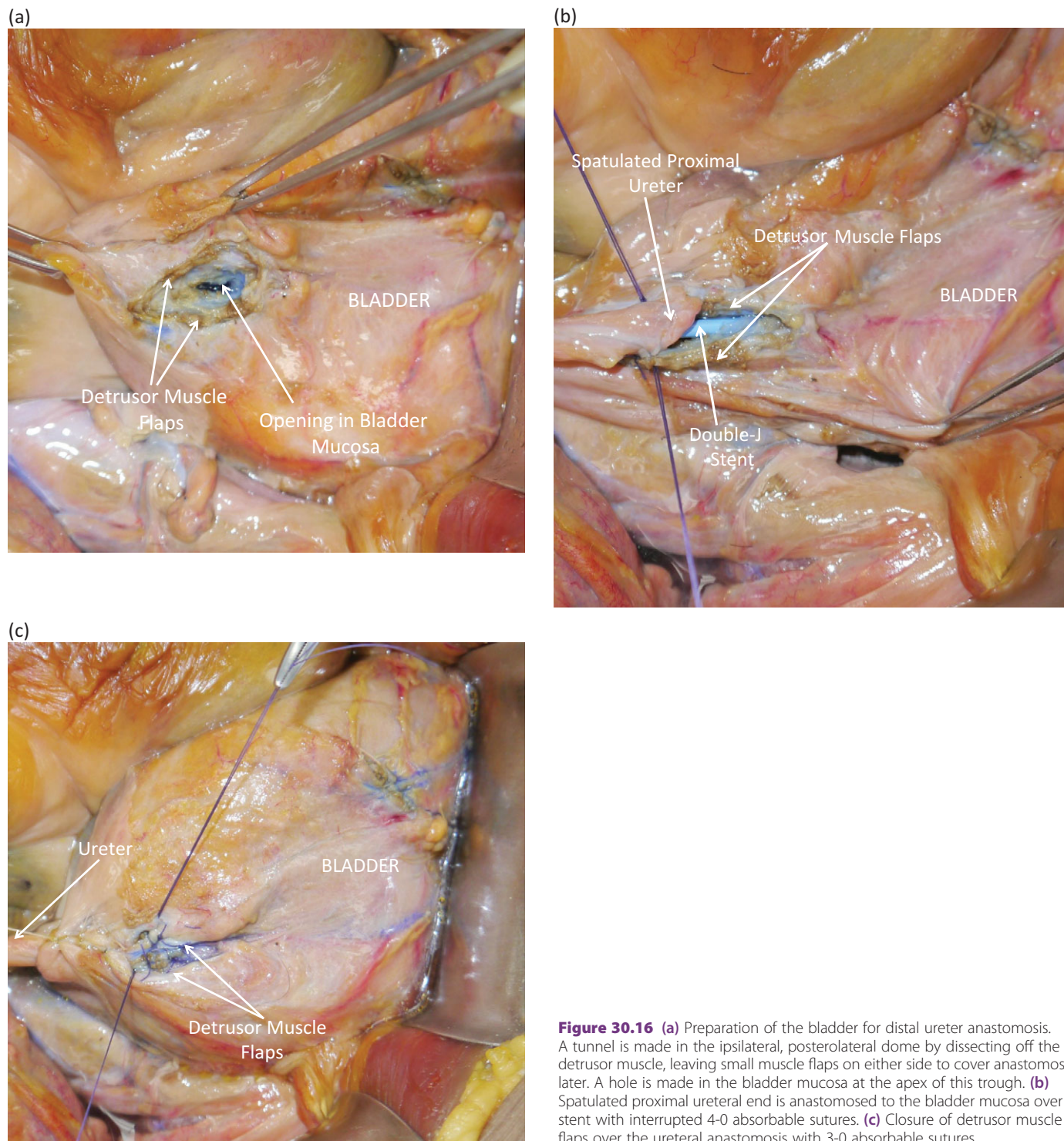


Figure 30.16 (a) Preparation of the bladder for distal ureter anastomosis. A tunnel is made in the ipsilateral, posterolateral dome by dissecting off the detrusor muscle, leaving small muscle flaps on either side to cover anastomosis later. A hole is made in the bladder mucosa at the apex of this trough. (b) Spatulated proximal ureteral end is anastomosed to the bladder mucosa over a stent with interrupted 4-0 absorbable sutures. (c) Closure of detrusor muscle flaps over the ureteral anastomosis with 3-0 absorbable sutures.

be anastomosed over a stent with interrupted 4-0 vicryl suture. The muscle flaps are then laid over the ureter in this trough, and secured with 3-0 vicryl absorbable suture.

- If the distal anastomosis cannot be performed tension-free, the bladder may be mobilized to the transected ureter to perform a “psoas hitch.” The bladder is opened vertically and obliquely towards the side of the injury. The lateral peritoneal attachments are then divided as needed for mobilization. The bladder body can then be displaced towards the side of the injury and sutured to the psoas muscle with 2-0 nonabsorbable suture. The distal ureter can then be reimplanted into the bladder using a tunneled anti-refluxing anastomosis with a stent. The bladder is then closed in two layers with 2-0 or 3-0 absorbable sutures.
- If there are adjacent vascular or visceral repairs, every attempt should be made to isolate the ureteral repair by placing an omental pedicle flap over the repair to prevent fistula formation.
- Tissue sealant may be applied to the area of anastomosis.
- Place drains after the repair.

Technique of Ureteral Double-J Stent Placement

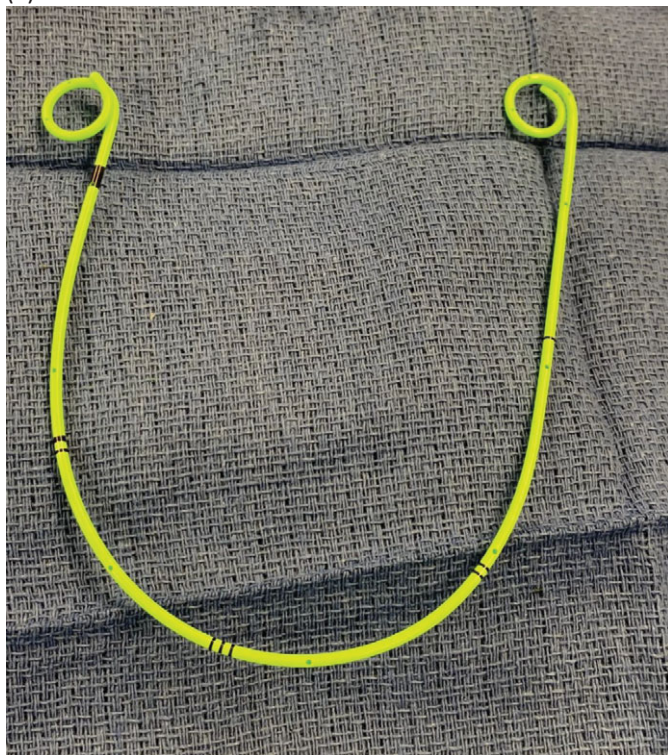
- Ureteral stent placement is strongly recommended if upper or lower urinary tract extravasation is encountered or

suspected. Ureteral stent placement carries minimal associated morbidity over the short-term and can facilitate proper healing and patency of the lower urinary tract.

- Intraoperatively, the stent may be inserted through the ureteric orifice in the bladder or the ureteric injury.
- As a first step for ureteral stent placement, a soft, flexible guidewire is carefully placed through the ureteric injury or the ureteric orifice in the bladder, and advanced into the renal pelvis. There should be minimal force applied to the wire as advanced. Some resistance will be felt as the stent curls upon entry into the renal pelvis.

The double-J stent is then inserted in a retrograde fashion, over the guidewire. As the wire is held on gentle traction, the stent is advanced into the renal pelvis. If the stent is placed through a ureteric injury, the same process is repeated for placement of the distal part of the stent into the bladder. If the stent is placed through the ureteric orifice, the distal 3–4 cm should be exposed in the bladder. The wire is then removed.

(a)



(b)

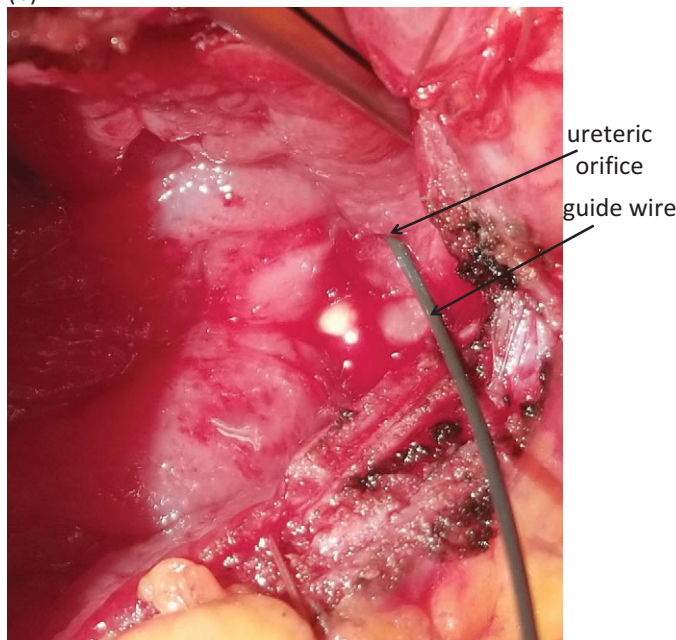
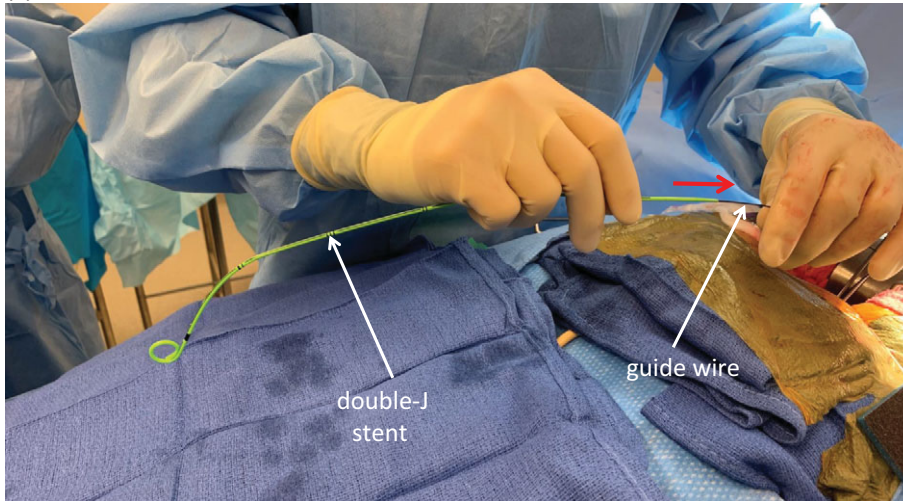


Figure 30.17 (a) Double-J stent. One loop is positioned in the renal pelvis and the other in the bladder. (b) A soft, flexible guidewire is carefully placed through the ureteric orifice in the bladder and advanced into the renal pelvis. (c) The double-J stent is then inserted in a retrograde fashion over the guidewire. As the wire is held on gentle traction, the stent is advanced (red arrow) into the renal pelvis. (d) The distal 3–4 cm of the double-J stent (circle) is exposed in the bladder (stent was placed through ureteric orifice in the bladder).

(c)



(d)

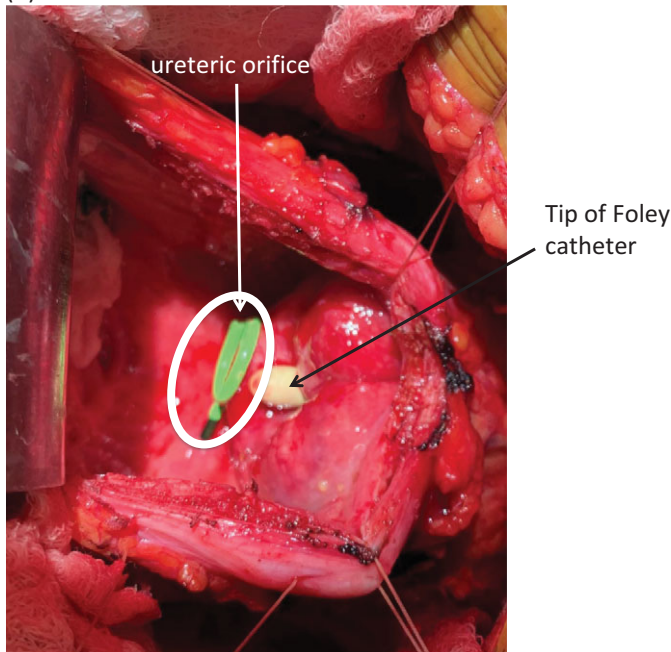


Figure 30.17 (cont.)

- The ureteric stent is kept in place for 4–6 weeks. The stent may be removed in the office or in the operating room.

Technical Pitfalls

- Avoid extensive dissection of the surrounding tissues during mobilization of the ureter. The ureter receives its blood supply from the surrounding tissues medially, and extensive dissection may cause ischemia of the repair site and either stricture or break-down of the anastomosis.
- Failure to use a double-J stent or spatulate the ends of the ureter when doing the primary repair increases the risk of anastomotic stricture.

- When performing reimplantation, ensure there is no acute angulation of the ureter as it enters the bladder, as acute angulation will prevent adequate drainage of the ureter.

Postoperative Care

- Drains should be left in the retroperitoneum until the output is minimal. Internal stents should be removed endoscopically through the bladder 4–6 weeks post injury, followed by excretory urography or retrograde pyelography to demonstrate a patent anastomosis without any evidence of urine leak. Ureteral patency should be reassessed again after three months with excretory urography or renal ultrasound to assess for hydronephrosis.

- Ureteric double-J stents can be removed cystoscopically, a few weeks after placement, after intravenous pyelography evaluation to rule out any ureteric leaks.

Bladder Injury

General Principles

- Injuries to the bladder are classified according to the location of rupture. Intraperitoneal bladder rupture always requires operative repair. Extraperitoneal ruptures can be managed with urethral catheter drainage alone. Some

bladder injuries can be a combination of both intraperitoneal and extraperitoneal ruptures and should be fixed surgically.

Repair of Bladder Injury

- Intraperitoneal bladder ruptures almost always involves the dome of the bladder. Inspect and palpate the bladder through the laceration to verify that there are no other injuries and that there is clear efflux from both ureteral orifices. If necessary, the laceration can be extended to adequately visualize the inner surface of the bladder.

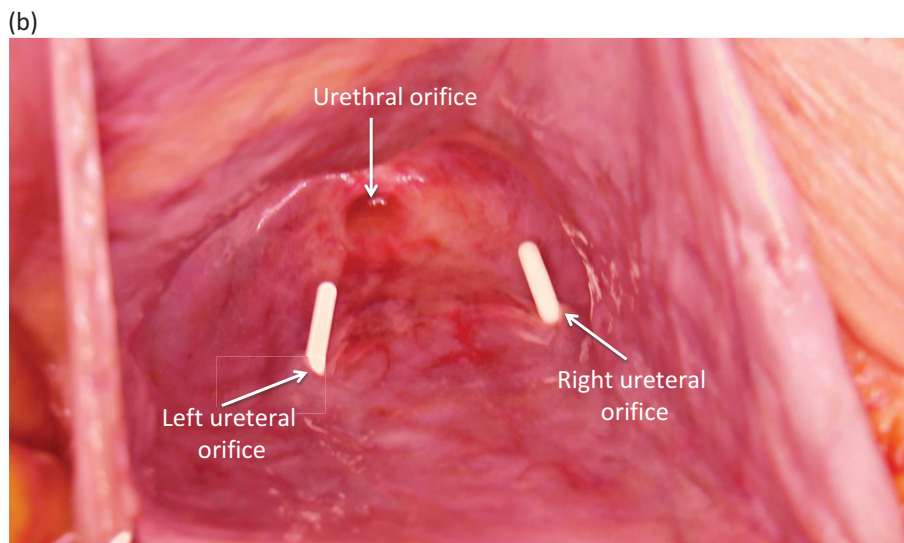
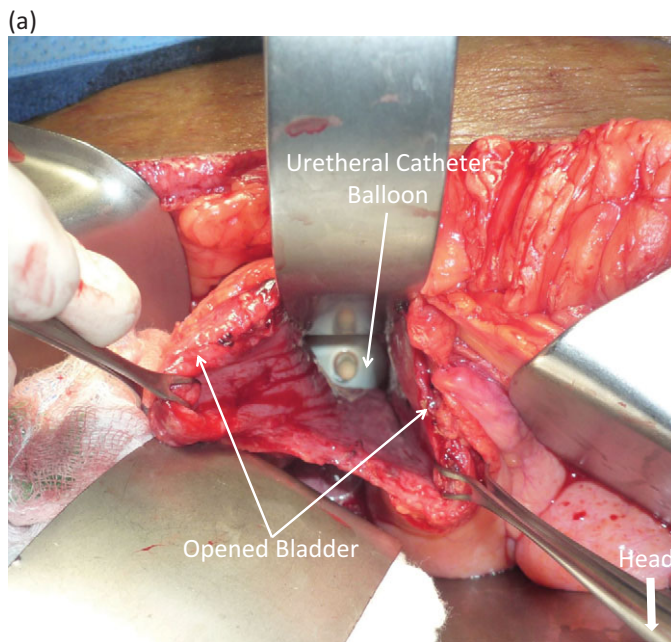
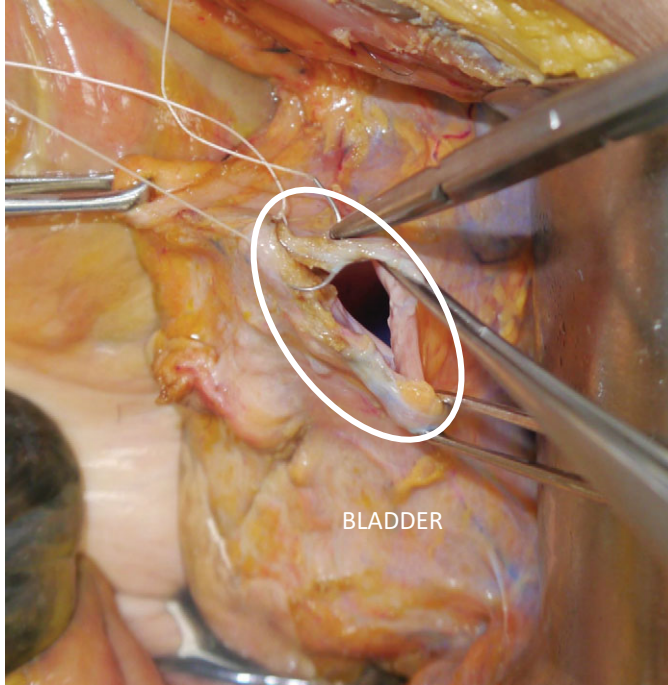


Figure 30.18 (a) Intraperitoneal bladder rupture with laceration extended into an anterior midline cystotomy to fully visualize the inside of the bladder.

- Debride any devitalized tissue.
- If extraperitoneal lacerations are seen on exam, close them from inside the bladder with a single layer of interrupted 3-0 or 4-0 absorbable sutures.
- Once inspection and repair of extraperitoneal lacerations are complete, close the laceration in two layers using 2-0 or 3-0 absorbable sutures.
- Place a drain near the repair.

(a)



(b)

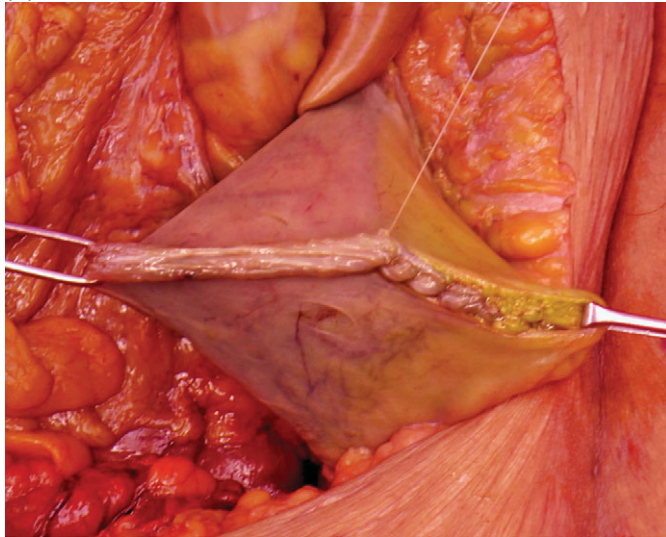


Figure 30.19 (a, b) Intraperitoneal bladder laceration (circle) repaired in two layers using 3-0 absorbable sutures.

Postoperative Care

Intraperitoneal drains should be left in place until output is minimal. The urethral catheter should be left in place for 7–10 days. If there is any concern about bladder healing, a cystogram can be performed to evaluate for urine leakage from the repair. This should be considered for all complex repairs, and those involving the trigone of the bladder.

Technical Pitfalls

- In penetrating injuries with no accountable second bladder wound, always examine the bladder from the inside in order to avoid missed injuries.
- Test the closure by instilling the bladder with sterile irrigation through the existing urethral catheter. Any significant leaks may be oversewn with 3-0 absorbable sutures in a figure-of-eight fashion. Tiny leaks will most likely seal on their own. Tissue sealant may be applied.

Abdominal Aorta and Splanchnic Vessels

Pedro G. Teixeira, Gregory A. Magee, and Vincent L. Rowe

Surgical Anatomy

- For vascular trauma purposes the abdomen is divided into four retroperitoneal anatomical areas:
 - Zone 1: The midline retroperitoneum from the aortic hiatus to the sacral promontory is broken into supramesocolic and inframesocolic areas. The supramesocolic area contains the suprarenal aorta and its major branches (celiac artery, superior mesenteric artery, and renal arteries), the supramesocolic segment of the inferior vena cava with its major branches, and the superior mesenteric vein. The inframesocolic area contains the infrarenal aorta and infrarenal inferior vena cava.
 - Zone 2 (left and right): This is the paired right and left region lateral of Zone 1 containing the kidneys and renal vessels.
 - Zone 3: The pelvic retroperitoneum, which contains the iliac vessels.
- The abdominal aorta originates between the two crura of the diaphragm at the level of T12–L1 and bifurcates into the common iliac arteries at the level of L4–5. The umbilicus is an approximate external landmark for the aortic bifurcation. The first large branch is the celiac trunk, followed by the superior mesenteric artery 1–2 cm inferiorly, and both course anteriorly and inferiorly. The renal arteries originate 1–2 cm below the origin of the superior mesenteric artery at the level of L2 and course laterally. Finally, the inferior mesenteric artery originates 2–5 cm above the aortic bifurcation on the left anterior aspect of the aorta.

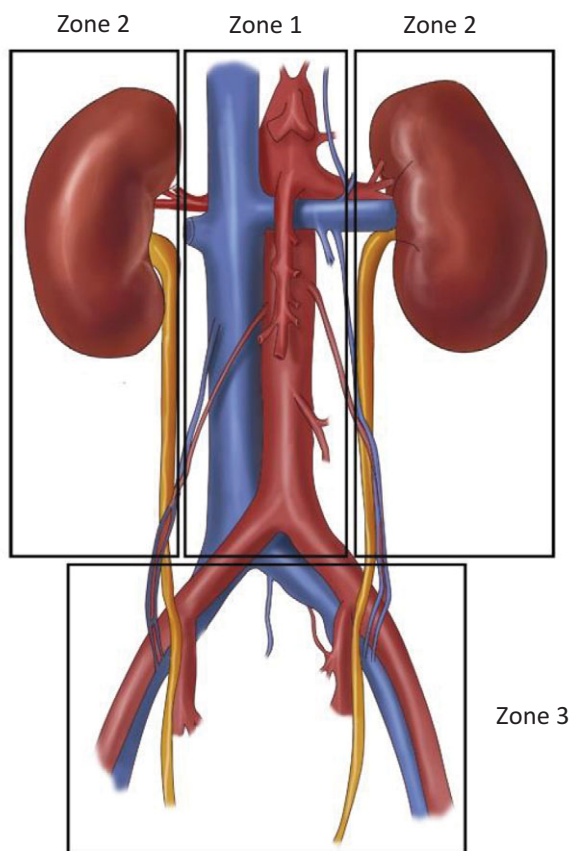


Figure 31.1 Retroperitoneal vascular zones. Zone 1 includes the midline vessels from the aortic hiatus to the sacral promontory; Zone 2 the paracolic gutter and the kidneys; Zone 3 the pelvic retroperitoneum.

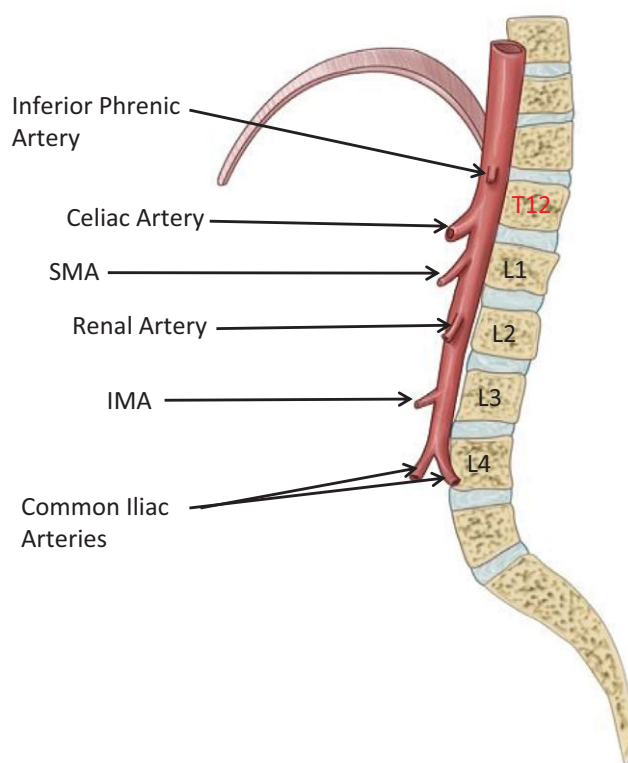


Figure 31.2 Lateral view of the major abdominal branches of the aorta. Note the tight concentration of the supramesocolic vessels: celiac artery, superior mesenteric artery (SMA), and renal arteries.

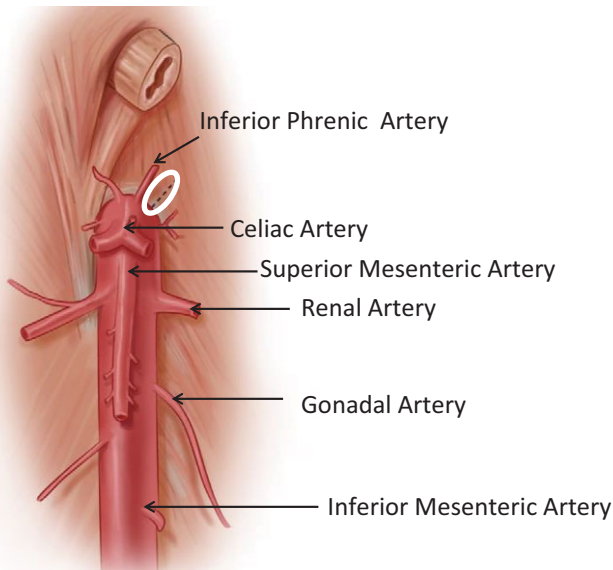


Figure 31.3 Anatomy of the major branches of the abdominal aorta. Note the site of division (dashed line) of the left crus of the diaphragm at 2 o'clock to avoid the inferior phrenic artery for exposure of the lower thoracic aorta.

- **Celiac artery:** The main trunk originates on the anterior surface of the aorta at the level of T12–L1. It is 1–2 cm long and divides into three branches at the upper border of the pancreas—the common hepatic, left gastric, and splenic arteries. The celiac is encased in extensive fibrous, ganglionic, and lymphatic tissues, which makes surgical dissection of the celiac artery difficult. In 10–20% of patients, the left gastric artery gives off a replaced left hepatic artery that courses through the gastrohepatic omentum and can be injured while mobilizing the left lobe of the liver or lesser curve of the stomach.
- **Superior mesenteric artery (SMA):** The SMA originates from the anterior surface of the aorta at the level of L1, 1–2 cm below the celiac artery. It courses posterior to the neck of the pancreas and anterior to the third part of the duodenum, beyond which it enters the root of the mesentery. SMA branches include the inferior pancreaticoduodenal artery, the middle colic artery, an arterial arcade with 12–18 intestinal branches, the right colic artery, and the ileocolic artery. In 10–20% of patients, the SMA gives off a replaced right hepatic artery, which courses posterior to the head of the pancreas and runs posteriorly and to the right of the portal vein.
- **Renal arteries:** The right renal artery emerges at a slightly higher level and is longer than the left and courses posteriorly to the inferior vena cava. Approximately 30% of patients have more than one renal artery, usually an accessory artery supplying the lower pole of the kidney. Both renal veins lie anteriorly of their accompanying renal arteries. The left renal vein is significantly longer than the right and courses anteriorly to the aorta. The left renal vein drains the left gonadal vein inferiorly, the left adrenal vein superiorly, and the renolumbar vein posteriorly. The right gonadal vein drains directly into the IVC.
- **Inferior mesenteric artery (IMA):** The IMA provides blood supply to the left colon, sigmoid, and the rectum. It communicates with the SMA through the marginal artery of Drummond and arc of Riolan.

General Principles

- Abdominal and pelvic vascular injuries result in noncompressible hemorrhage. Immediate operative intervention is the cornerstone of survival.
- Penetrating abdominal vascular injuries are usually associated with hollow viscus injuries, which increase the complexity of the operation and expose the vascular repair to enteric contamination.
- In patients with multiple potentially fatal injuries, who are too unstable to undergo definitive repair of a critical vessel, a temporary shunt can be placed with a plan for delayed definitive reconstruction.
- Abdominal arterial and venous injuries occur with the same incidence. The most commonly injured abdominal vessel is the IVC, followed by the aorta, due to their relative size.
- In suspected abdominal vascular injuries, where the IVC or iliac veins may be injured, the common femoral veins should not be used for venous access.
- Patients with severe intra-abdominal hemorrhage compensate their central blood pressure by maximal peripheral vasoconstriction and as such, they are at high risk of rapid decompensation and cardiac arrest during induction of anesthesia that causes peripheral vasodilation. Therefore, the patient should be prepared and draped, with the surgical team ready to commence the operation prior to the induction of anesthesia, whenever possible.
- The feasibility of systemic anticoagulation with heparin is limited by trauma-induced coagulopathy; however, heparinized saline (5,000 units in 100 mL saline) should be liberally injected into injured vessels with little risk of worsening bleeding.
- Approximately 15% of patients with intra-abdominal vascular injuries arrive in cardiac arrest. These patients may benefit from a left anterolateral resuscitative thoracotomy and cross-clamping of the thoracic aorta. Resuscitative endovascular balloon occlusion of the aorta (REBOA) should be used with caution in patients with concern for aorta or iliac artery injuries, as blind placement of the REBOA catheter can worsen these injuries.

Special Surgical Instruments

- In addition to a standard trauma laparotomy instrument tray, vascular clamps and needle drivers with multiple lengths and angulations must be available.
- A self-retaining retractor, such as Omni-Tract or Bookwalter is extremely helpful in providing adequate exposure.
- A U-shaped aortic compression device should be available for temporary aortic control just below the diaphragm. If this is not available, a sponge stick or manual pressure can be used.
- Surgical headlamp and magnifying loupes are useful.

- A thoracotomy instrument tray with a Finochietto retractor should be available, should a left anterolateral thoracotomy be necessary, for aortic cross-clamping.

Positioning

- Supine, with upper extremities abducted to 90°. Skin antiseptic preparation should include the chest, abdomen, and thighs, in anticipation of a possible thoracotomy or venous conduit harvesting.

Incision

- Extended midline trauma laparotomy, from xiphoid to pubic symphysis.
- For proximal aortic control in cases with high supramesocolic bleeding or hematoma, a left anterolateral thoracotomy through the fifth intercostal space may be needed. REBOA is rarely useful in this situation, as supramesocolic aortic reconstruction will require its removal.

Exposure

- Upon opening the peritoneal cavity, the usual findings include free intraperitoneal bleeding, or a retroperitoneal hematoma, or a combination of the two. The retroperitoneal hematoma may or may not be expanding or pulsatile. Intraperitoneal hemorrhage can be due to solid organ injury, mesenteric injury, or major vascular injury and the surgeon needs to evaluate for each.
- The management of retroperitoneal hematomas depends on the mechanism of injury.
 - As a general rule, almost all hematomas due to penetrating trauma should be explored, irrespective of size. Often, underneath a small hematoma there is a vascular or hollow viscus perforation. The only exception to this recommendation is a stable and nonexpanding retrohepatic (Zone 4) hematoma. Surgical exploration of the retrohepatic vena cava or the hepatic veins is challenging and may result in uncontrollable bleeding. If, for some reason, a hematoma is not explored, postoperative CT angiographic evaluation should be considered.
 - Retroperitoneal hematomas due to blunt trauma rarely require exploration because of the very low incidence of underlying vascular or hollow viscus injuries requiring surgical repair. The only indications for exploration of hematomas due to blunt trauma include a paraduodenal hematoma, large expanding or leaking hematoma, and a hematoma in the region of the superior mesenteric artery associated with ischemic bowel.

Exploration of Zone 1

Supraceliac Aortic Control

- Proximal control and direct compression or cross-clamping of the distal thoracic and proximal abdominal aorta can be achieved below the diaphragm, through a midline laparotomy, in most cases.

- At the aortic hiatus of the diaphragm, the aorta is surrounded by dense connective, nervous, and lymphatic tissue, which makes the exposure difficult. However, more proximally, at the distal thoracic aorta level, the vessel is free from this dense periaortic tissue and can be exposed much easier. This segment is accessible through the esophageal hiatus.

- The first step for this approach is to mobilize the left lobe of the liver. The ligamentum teres and the falciform ligament are divided with electrocautery. The left triangular ligament of the liver is then divided. This maneuver is facilitated by positioning the surgeon's right hand behind the left lobe of the liver and using the right thumb to retract the liver caudad. The left triangular ligament is then divided with electrocautery over the surgeon's right index finger, and the left lateral segment of the liver is folded medially, exposing the aortic hiatus.

(a)

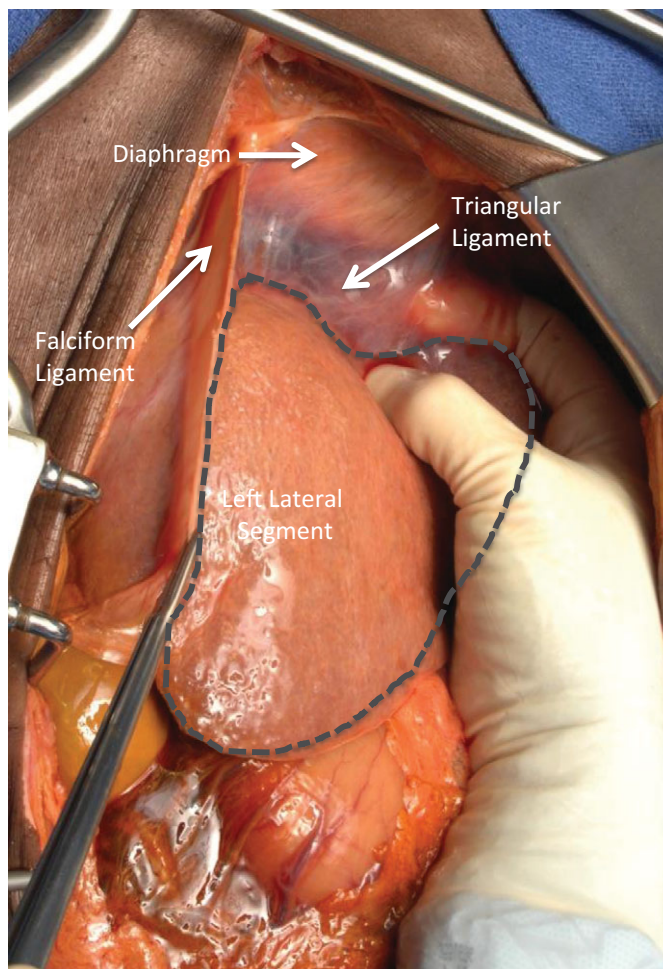
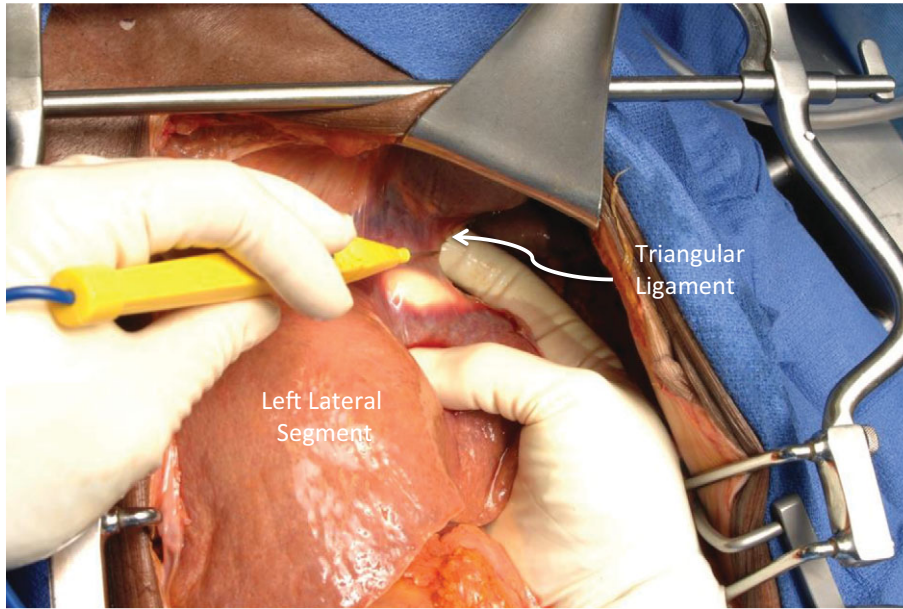


Figure 31.4 (a) Mobilization of the left lateral segment of the liver to expose the area of the esophageal hiatus. The falciform ligament has been divided and the surgeon's right index finger is positioned posteriorly to the left triangular ligament of the liver. (b) Division of the left triangular ligament of the liver with electrocautery. This maneuver allows the left lateral segment to be retracted medially to expose the area of the gastroesophageal junction. (c) The left lateral segment of the liver has been retracted medially, exposing the esophageal hiatus.

(b)



(c)

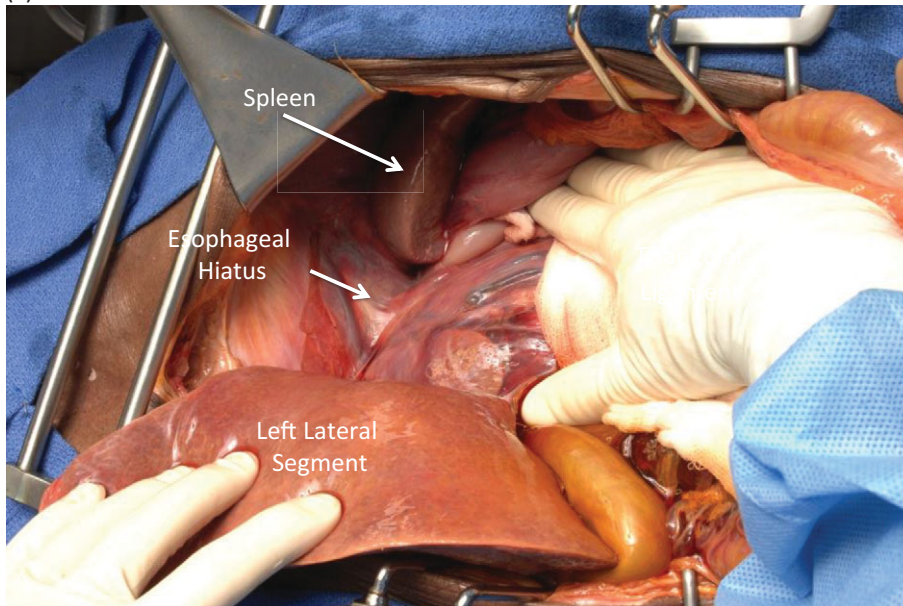
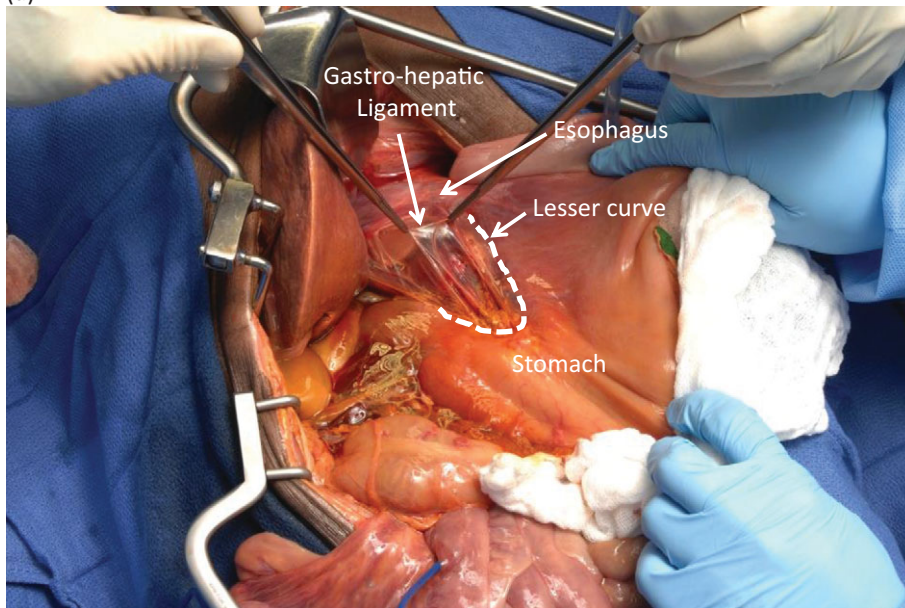


Figure 31.4 (cont.)

- While the left lobe of the liver is folded medially, the stomach is retracted to the patient's left and downwards to expose the gastrohepatic ligament. The ligament is then divided, exposing the crura of the diaphragm.
- The esophagus is circumferentially dissected at the gastroesophageal junction and encircled with a Penrose drain for traction.
- The left diaphragmatic crus is then divided at the 2 o'clock position.
- Using blunt digital dissection, the distal thoracic aorta is isolated and a DeBakey or Cooley aortic clamp is applied. Blind application of a clamp in this area is ineffective as it will invariably slip off and may cause iatrogenic injury.

(a)



(b)

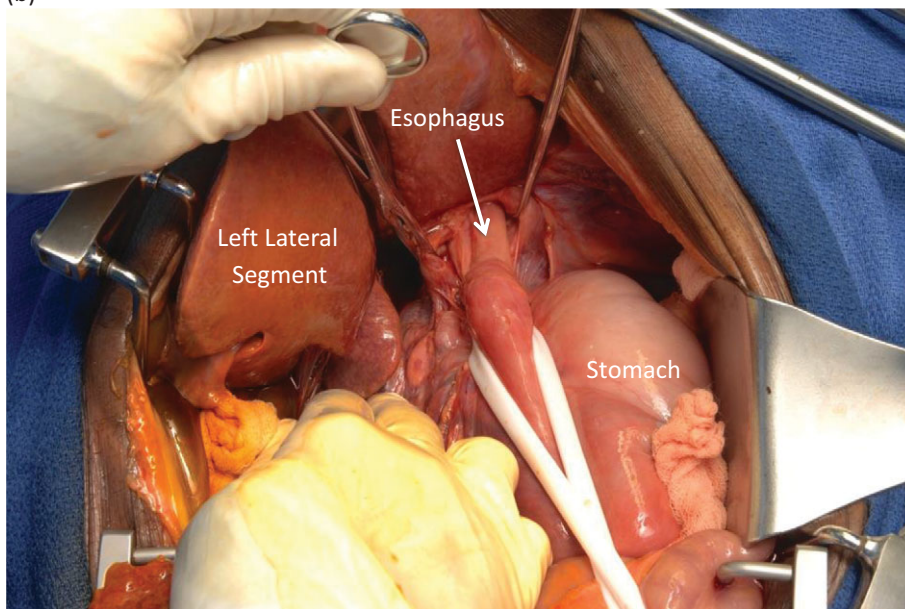
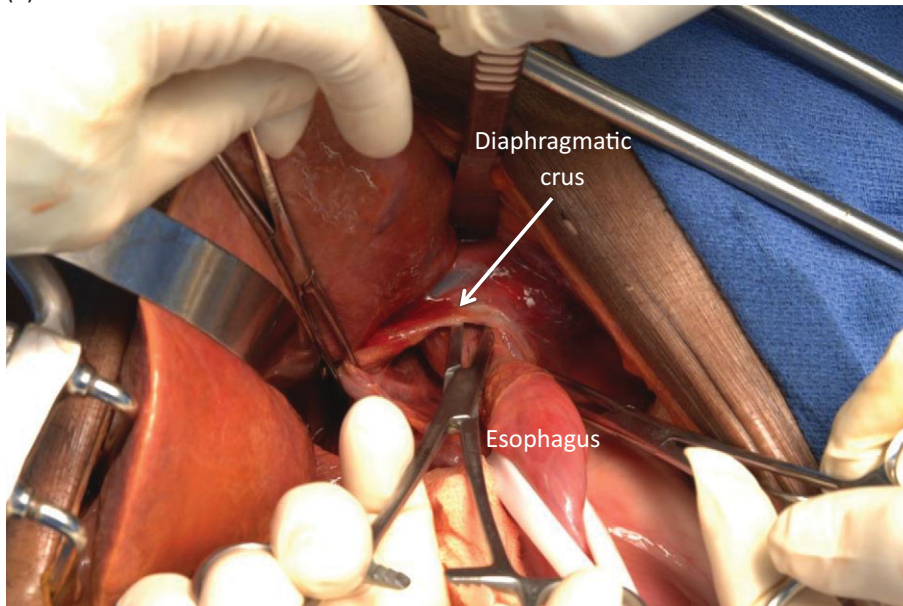


Figure 31.5 (a) The stomach is retracted caudad and the gastrohepatic ligament is divided. (b) After the esophagus is circumferentially dissected at the gastroesophageal junction, a Penrose drain is positioned around it for traction. Note the use of Allis clamps to retract the diaphragmatic crus fibers.

(a)



(b)

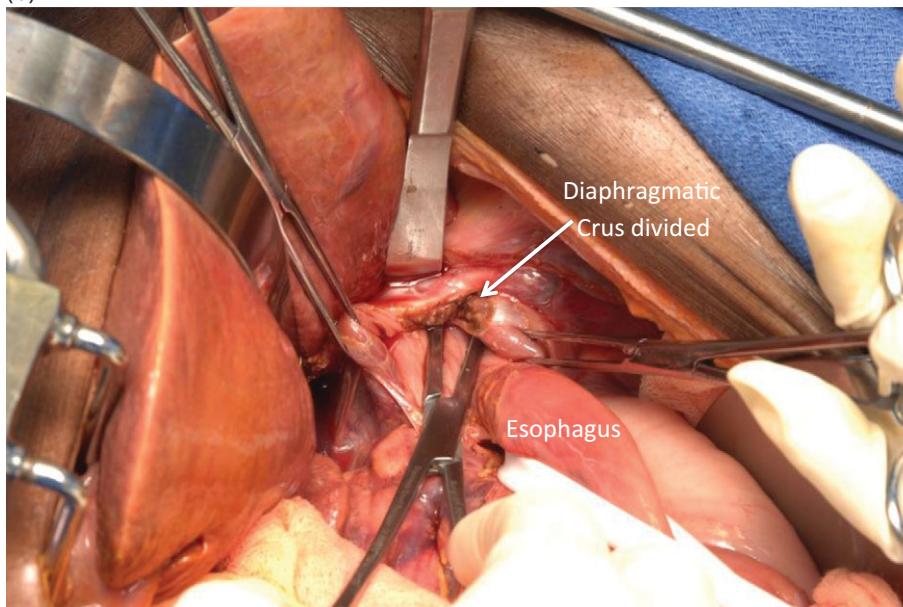
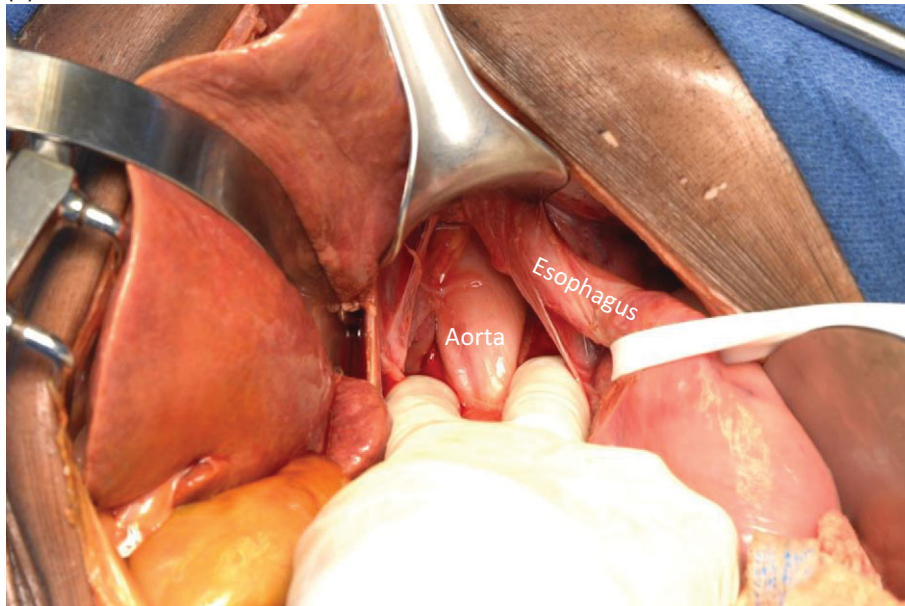
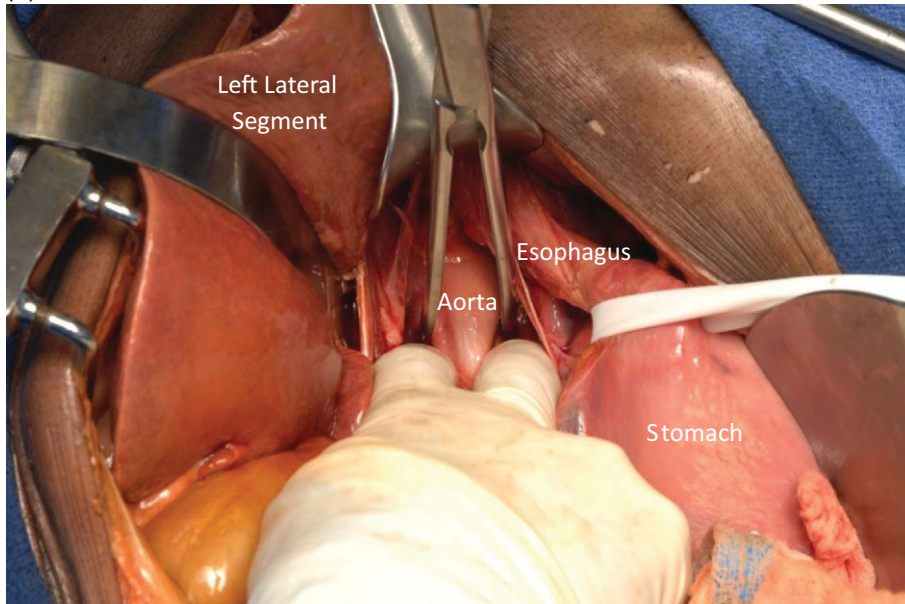


Figure 31.6 (a) With the esophagus retracted downwards, a Peon clamp is advanced into the esophageal hiatus of the diaphragm to facilitate the division of the muscle fibers. (b) The diaphragmatic crus is divided at 2 o'clock position.

(a)



(b)



(c)

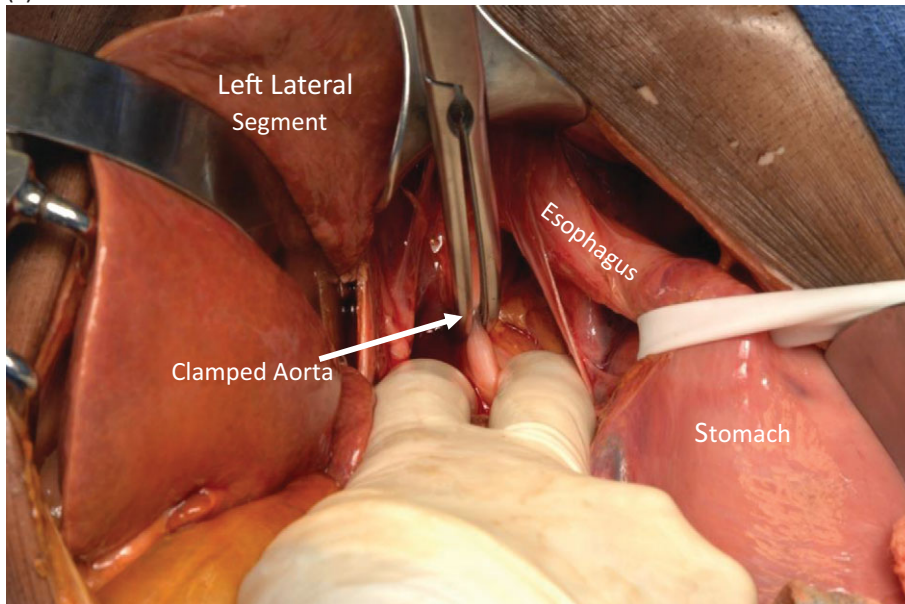


Figure 31.7 (a) The distal thoracic aorta has been identified and isolated. Note how at this level the aorta is free from surrounding connective, nervous, and lymphatic tissue. (b) A DeBakey aortic clamp is applied to the aorta. Note the esophagus retracted laterally and protected from inadvertent injury with the application of the clamp. (c) Aortic control achieved by vascular clamp successfully applied to the distal thoracic aorta.

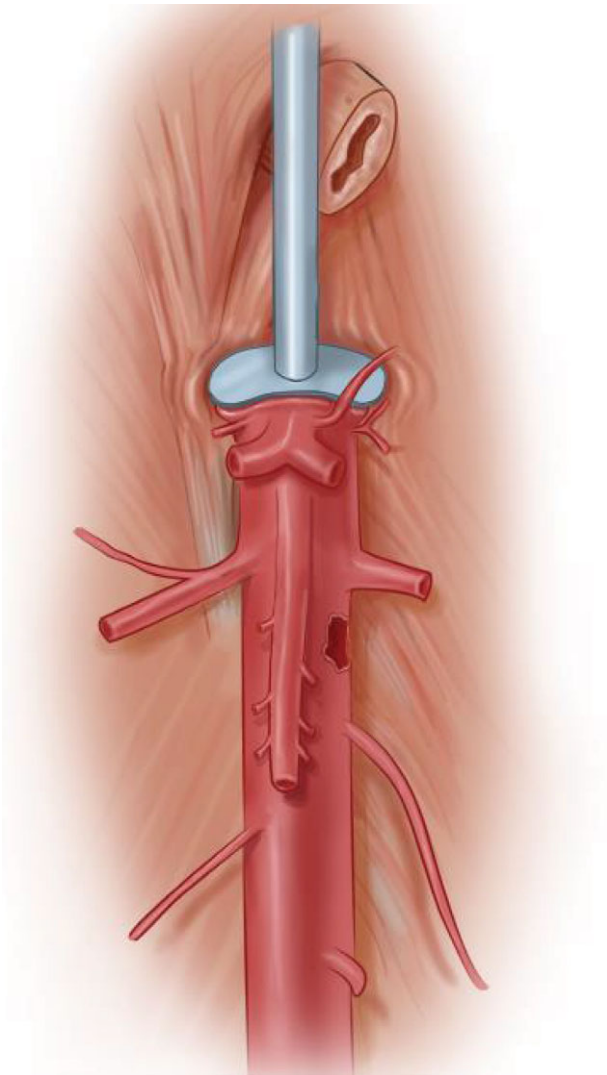


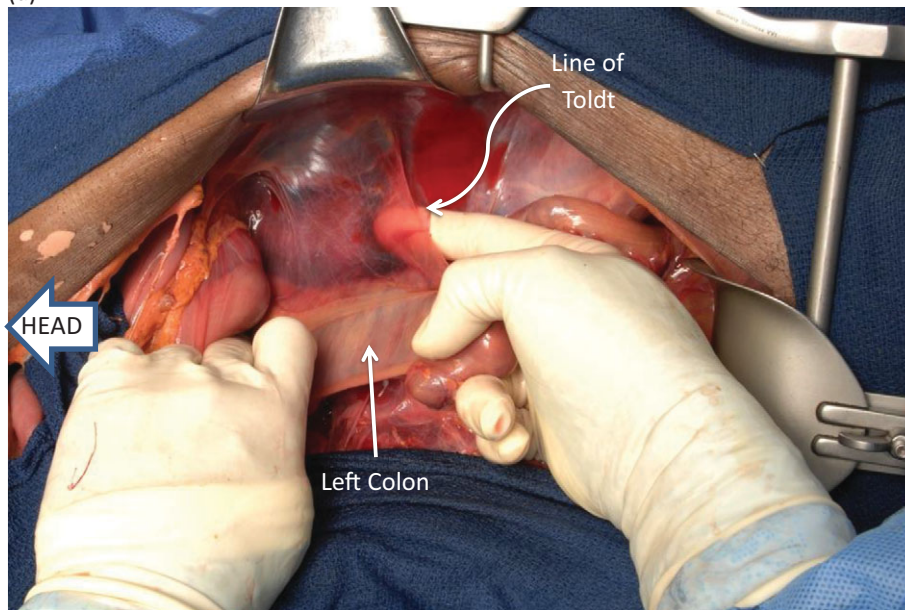
Figure 31.8 Aortic compression device applied on the supraceliac aorta through the lesser sac. The aorta is compressed against the spine.

- An alternative strategy for rapid temporary supraceliac aortic control is the utilization of a U-shaped aortic compression device. This handheld device is positioned over the supraceliac aorta through the lesser sac. Applying constant anteroposterior pressure, the device compresses the aorta against the spine until definitive control of the bleeding is achieved. The advantage of this technique is the minimal dissection needed for application of the device, but a second assistant is required to hold pressure while definitive bleeding control is pursued.
- In cases with a high supramesocolic hematoma, where infradiaphragmatic exposure of the aorta is difficult or not possible, a left thoracotomy is necessary for aortic control.

Exposure of the Supramesocolic Aorta and Visceral Branches

- Zone 1 supramesocolic bleeding or hematomas are the most difficult to approach because of the dense concentration of major vessels (aorta, celiac artery, superior mesenteric artery, renal vessels, inferior vena cava), the difficult exposure of many of these vessels, and the difficult proximal control of the infradiaphragmatic aorta.
- The supramesocolic aorta with the origins of its major visceral branches is best exposed by left medial visceral rotation, with or without mobilization of the left kidney.
 - The first step of this approach is the division of the peritoneal reflection lateral to the left colon (white line of Toldt) and reflection of the left colon off the lateral abdominal wall. The retroperitoneal plane is developed posterior of the left kidney in most circumstances, or anteriorly to the Gerota's fascia, if the intention is to leave the left kidney in place.

(a)



(b)

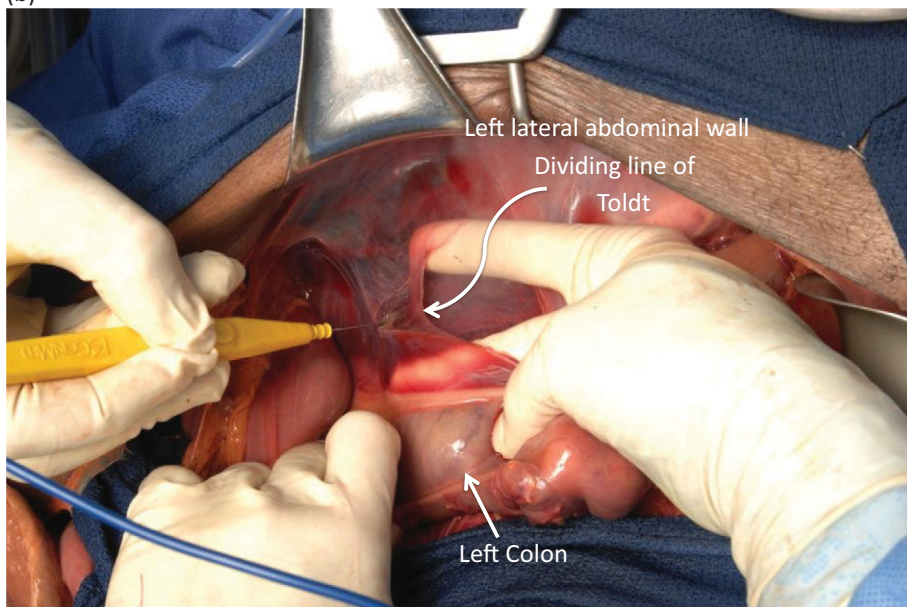


Figure 31.9 (a) Left medial visceral rotation. Traction of the descending colon exposes the left peritoneal reflection and the white line of Toldt is identified. (b) The white line of Toldt being divided with cautery and the left colon is mobilized away from the lateral abdominal wall.

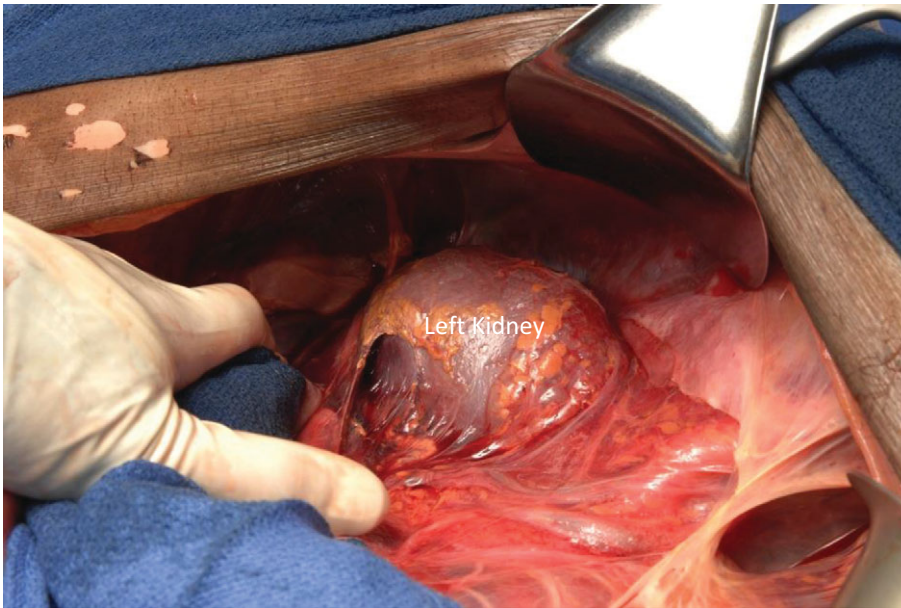


Figure 31.10 After division of the white line of Toldt, the plane between the left mesocolon and the left kidney is entered and the left colon mobilized medially. Note that the kidney was left at its original position.

- The retroperitoneal dissection is continued cephalad and the spleen is completely mobilized after division of the splenophrenic ligament. Avoid excessive traction to the splenic flexure of the colon or the spleen in order to prevent inadvertent avulsion of the splenic capsule and

bleeding. The spleen, fundus of the stomach, body and tail of the pancreas, colon, and small bowel are then rotated en bloc medially, exposing the entire aorta and origins of the celiac axis, superior mesenteric artery, and left renal artery.

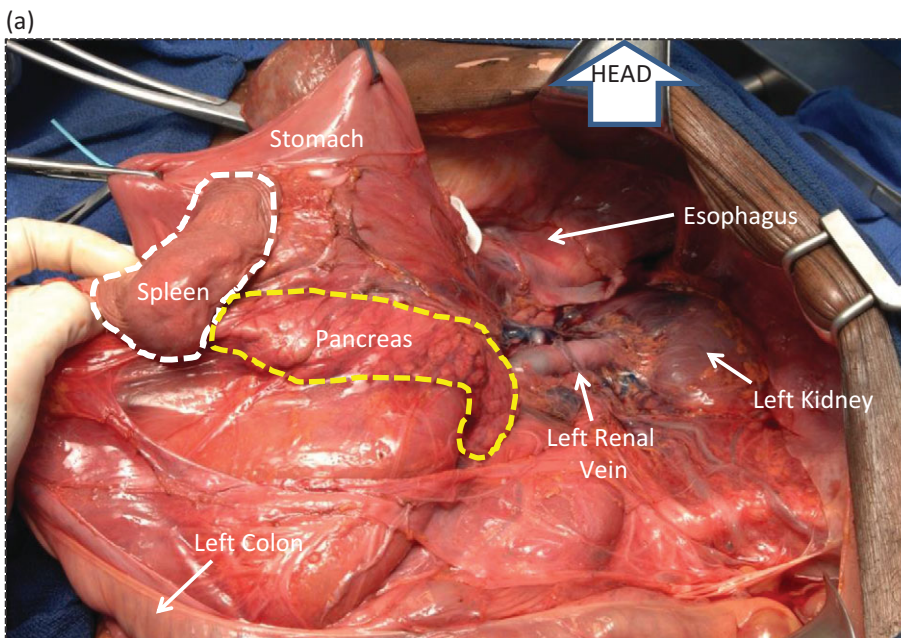


Figure 31.11 (a) Left medial visceral rotation has been performed after division of the splenorenal and splenophrenic ligaments. The pancreas and the spleen have been rotated medially en bloc. The posterior surface of the pancreas and its anatomical relationship with the spleen is depicted. The left kidney remains at its original position in the retroperitoneal. Note the left renal vein crossing anteriorly over the aorta. **(b)** Anatomy and visceral branches of the abdominal aorta.

(b)

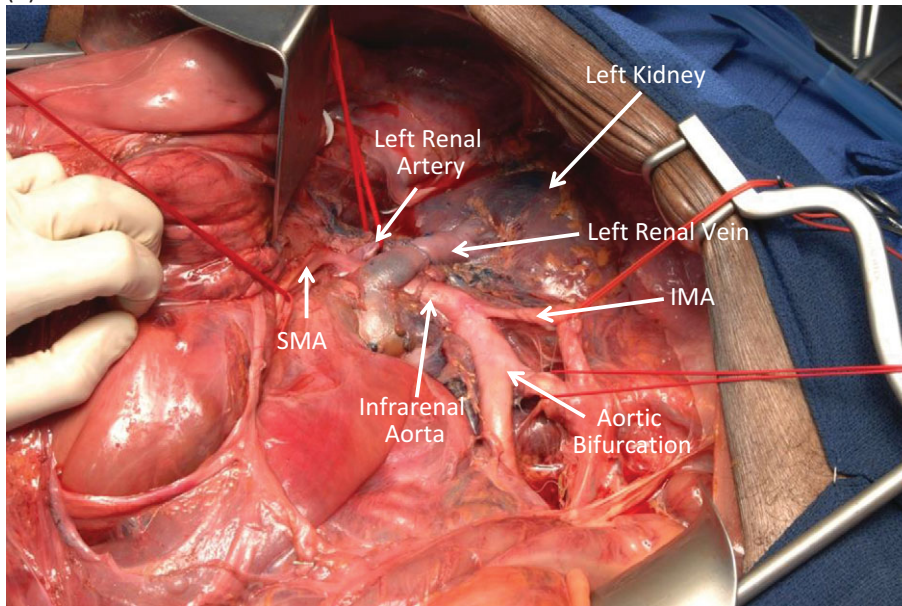


Figure 31.11 (cont.)

- Exposure of the aorta directly under the left renal vein may be difficult. In this case, there are three possible options: (1) Include the left kidney in the visceral rotation, (2) Mobilize the left renal vein, often after ligation and division of its three tributaries (left gonadal vein, left adrenal vein, and renolumbar vein), (3) Division of the left renal vein. In this case, the tributaries must be preserved and the left renal vein ligated and divided as close to the inferior vena cava as possible in order to maintain venous outflow for the left kidney.
- The left visceral rotation provides good exposure to the supramesocolic aorta and its major branches. However, it is associated with a significant risk of iatrogenic injury to the spleen and the body and tail of the pancreas.
- Following medial visceral rotation, exposure of the abdominal aorta is carried out by division of the tissues overlying its anterolateral surface.

Exposure of the Inframesocolic Aorta

- The inframesocolic abdominal aorta can be exposed directly by retracting the transverse colon cephalad and displacing the small bowel to the right. The peritoneum over the aorta is then incised and the aorta

is exposed. An alternative approach is medial rotation of the left colon.

Exploration of Zone 2

- Zone 2 is explored by mobilization and medial rotation of the right colon, the duodenum, and the head of the pancreas on the right side or the left colon on the left side. The source of bleeding in Zone 2 is usually the kidney or renal vessels.

Exploration of Zone 3

- The source of Zone 3 bleeding is usually the iliac vessels in penetrating injury and the pelvic bones, soft tissue, and venous plexus in blunt injury. This area is explored by incising the paracolic peritoneum and medial rotation of the right or sigmoid colon. An alternative approach is by direct dissection of the peritoneum over the vessels (see [Chapter 32 Iliac Vessels Injuries](#)).

Celiac Artery

- The celiac artery and its three branches can be approached directly through the lesser sac. Alternatively, exposure may be achieved through the previously described left medial visceral rotation. The rotation need not include the left kidney.

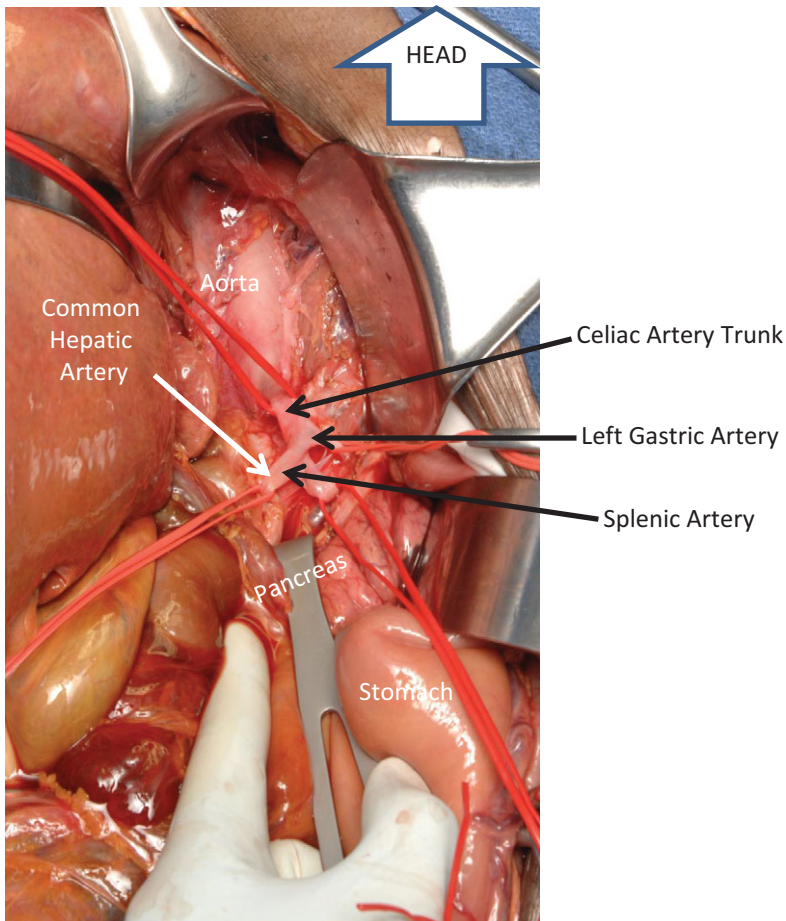


Figure 31.12 Anatomy of the celiac artery and its three proximal branches. Note that the median arcuate ligament and the celiac ganglion have been divided, exposing the anterior surface of the supraceliac aorta. The celiac artery trunk is noted as it branches into left gastric, splenic, and common hepatic arteries.

- It is rare that the celiac artery requires complex reconstruction. Ligation can be safely performed in all cases requiring anything more than simple arteriorrhaphy. Ischemic sequelae to the stomach, liver, or spleen are exceedingly rare because of the rich collateral circulation. The left gastric and splenic arteries may also be ligated with impunity. The common hepatic artery is the largest of the celiac artery branches and can be repaired with lateral arteriorrhaphy, end-to-end anastomosis, or venous interposition graft. Ligation of the artery proximal to the origin of the gastroduodenal artery is often well tolerated because of collateral blood supply from the gastroduodenal artery and portal vein. Transient elevation of liver enzymes lasting for a few days is common, but rarely has clinical significance. However, in some cases, especially in the presence of prolonged hypotension or associated liver injuries, segmental necrosis may be seen.

Superior Mesenteric Artery

- Anatomically, the SMA is divided into four zones: Zone 1, from the aortic origin to the inferior pancreaticoduodenal branch; Zone 2, from the inferior pancreaticoduodenal artery to the middle colic artery; Zone 3, distal to middle colic artery; and Zone 4, the segmental intestinal branches.
- An alternative anatomical classification system uses only two zones, the short retropancreatic segment and the segment inferior to the body of the pancreas, where it courses anterior to the uncinate process of the pancreas and the third part of the duodenum.
- Exposure of the SMA differs according to the location of the injury.
 - Exposure of the retropancreatic SMA can be achieved by left medial visceral rotation, as described above. The kidney does not need to be included in the rotation, unless there is a suspicion of injury to the posterior wall of the aorta.
 - In cases with severe bleeding, where immediate exposure of the retropancreatic SMA is critical, stapled division of the neck of the pancreas provides fast and direct exposure of the SMA and the portal vein. This technique has the considerable disadvantage of risk of pancreatic leak and requiring pancreaticojejunostomy or distal pancreatectomy.

(a)

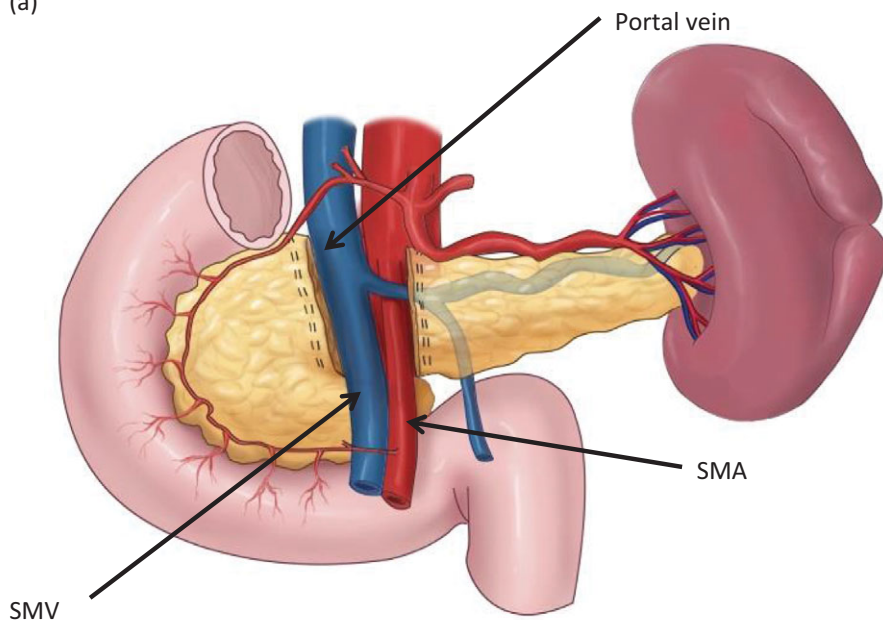
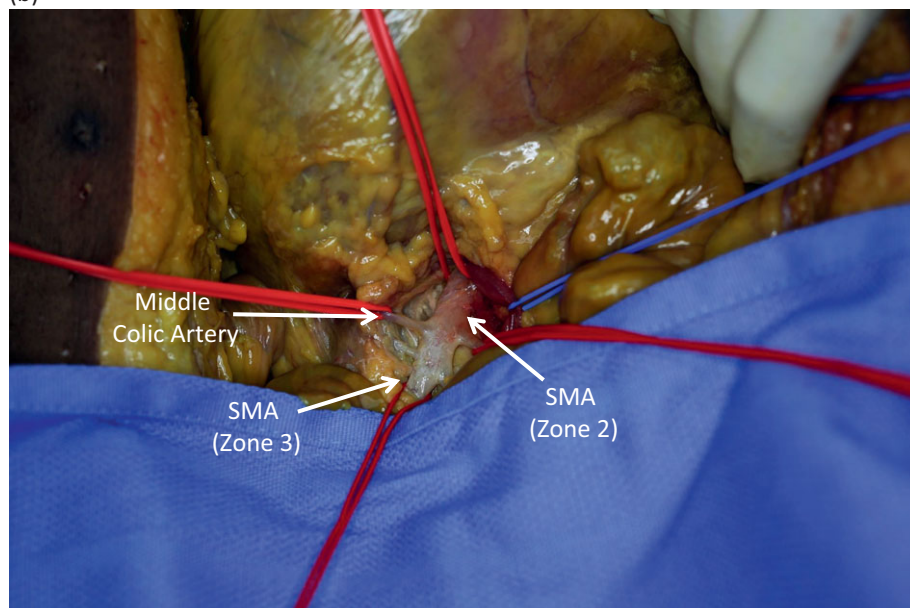


Figure 31.13 (a) In cases with severe bleeding, where immediate exposure of the retropancreatic SMA is critical, stapled division (GIA stapler) of the neck of the pancreas provides fast and direct exposure of the SMA and the portal vein. (b) Exposure of the SMA through the root of the mesentery.

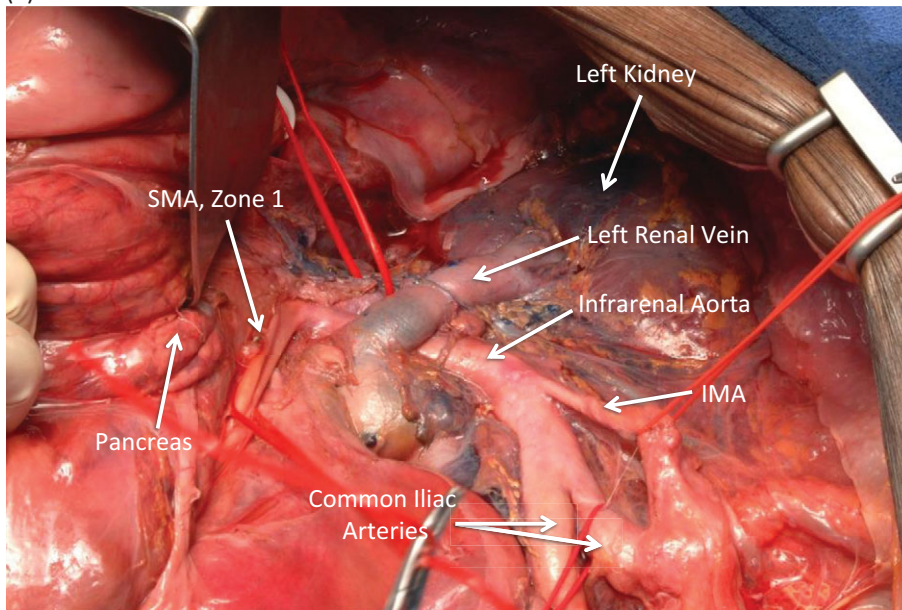
(b)



- Exposure of the infrapancreatic SMA can be achieved by cephalad retraction of the inferior border of the pancreas and direct dissection of the vessel. For more

distal injuries, exposure can be achieved with dissection through the root of the small bowel mesentery, to the right of the ligament of Treitz.

(a)



(b)

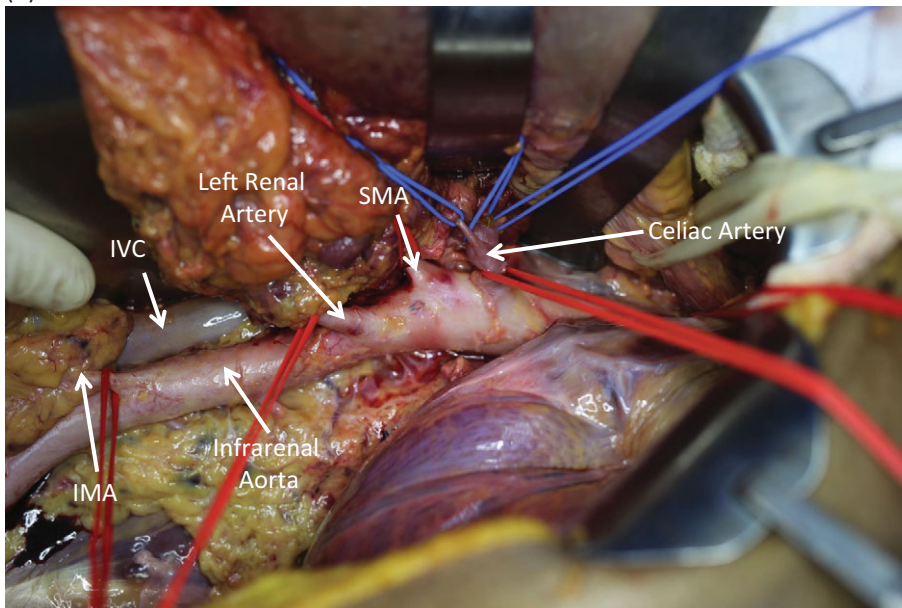


Figure 31.14 (a) After left medial visceral rotation, the retropancreatic SMA segment is exposed. Note the left kidney is left here. (b) After left medial visceral rotation with rotation of the left kidney, the entire lateral aspect of the abdominal aorta is exposed. Note here the left kidney rotated medially. (c) After left medial visceral rotation with rotation of the left kidney, the entire lateral aspect of the abdominal aorta is exposed. Note here the left kidney rotated medially.

(c)

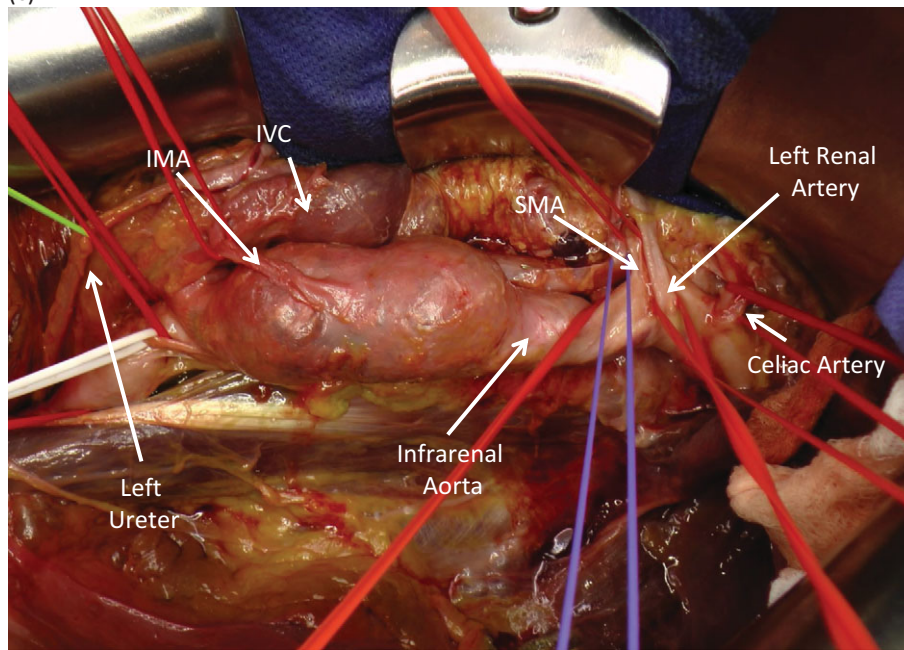


Figure 31.14 (cont.)

- In contrast to the celiac artery, ligation of the SMA results in variable degrees of ischemia according to the zone involved. Ligation at Zones 1 and 2 leads to extensive ischemia to the entire small bowel and right colon. Ligation at Zones 3 and 4 result in segmental small bowel ischemia. Unless irreversible bowel ischemia is present at laparotomy, ligation of the SMA, especially in Zones 1 and 2, should never be performed.
- Primary repair of the SMA may be possible in selected cases of sharp transection of the vessel, usually inflicted by knife wounds. The repair can be performed with 5-0 or 6-0 dual-armed polypropylene sutures.
- In the presence of even limited vessel tissue loss, an end-to-end anastomosis is rarely possible without excessive tension, because mobilization of the SMA is restricted due to the surrounding dense neuroganglionic tissue and its multiple branches.
- Management of complex SMA injuries not amenable to simple arteriorrhaphy should be determined by the condition of the patient, the site of the injury, and the experience of the surgeon. The surgical options for these patients include reconstruction with an interposition graft or damage control with temporary shunting.
 - Reconstruction of the very proximal SMA is usually performed with an autologous venous or synthetic graft between the distal stump of the SMA and the anterior surface of the aorta. For more distal injuries, an interposition venous graft between the transected ends of the vessel is usually required.
- For patients in critical condition with severe hypothermia, acidosis, and coagulopathy, a damage control procedure with a temporary endoluminal shunting should be considered. Definitive reconstruction should be performed as soon as possible after resuscitation and correction of coagulopathy and hypothermia. The technique of temporary endoluminal shunt placement is described in the specific peripheral vascular injuries chapters.
- Ligation of the proximal SMA results in ischemic necrosis involving the entire small bowel and the right colon. The first few centimeters of the jejunum may survive via collaterals from the superior pancreaticoduodenal artery. Ligation of the SMA proximal to the origin of the inferior pancreaticoduodenal artery may preserve critical collateral circulation to the proximal jejunum, but ligation of the SMA distal to the middle colic artery may be less likely to result in substantial bowel ischemia if the collateral circulation via the arc of Riordan and marginal artery of Drummond are intact. Ligation of the proximal SMA should be performed only in the presence of completely nonviable small bowel. Ligation should be avoided in all other circumstances because of the catastrophic consequences of short bowel syndrome.
- In the presence of an associated pancreatic injury, the vascular anastomosis should be performed away from the pancreas and be wrapped in an omental pedicle.

- Postoperatively, the patient should be monitored closely for any signs of bowel ischemia (lactic acidosis, leukocytosis, shock). Temporary abdominal closure and a planned second look laparotomy should be performed routinely to rule out bowel ischemia, as the consequences of delayed bowel perforation are catastrophic.

Renal Artery

- The left renal artery is more likely to sustain blunt trauma because the right renal artery is better protected from deceleration injuries due to its course posterior to the IVC.
- The management of renovascular injuries depends on the mechanism of injury, the warm ischemia time, the general condition of the patient, and the presence of a normal contralateral kidney.
 - Penetrating trauma almost always requires emergency operative intervention because of severe bleeding.
 - Blunt trauma to the renal artery usually results in thrombosis without bleeding. These cases may be managed nonoperatively or with endovascular stenting. In cases with avulsion of the artery, there is severe hemorrhage and an emergency operation is required.
 - In emergency operations for bleeding, a nephrectomy is usually the procedure of choice unless lateral arteriorrhaphy is possible.
 - Ligation of the right renal vein results in hemorrhagic infarction of the kidney and should always be followed by nephrectomy. However, ligation of the left renal vein near the IVC does not usually result in impaired renal outflow because of collateral venous drainage through the left gonadal, adrenal, and renolumbar veins.
- Exposure of the renal vessels
 - The left kidney and renal vessels can be quickly exposed by mobilization and medial rotation of the left colon. On the right side, mobilization of the right colon combined with a Kocher maneuver provides excellent visualization of the renal system. Bleeding control is then achieved by digital compression or application of a vascular clamp on the renal hilum. This is the most practical approach for trauma surgery.

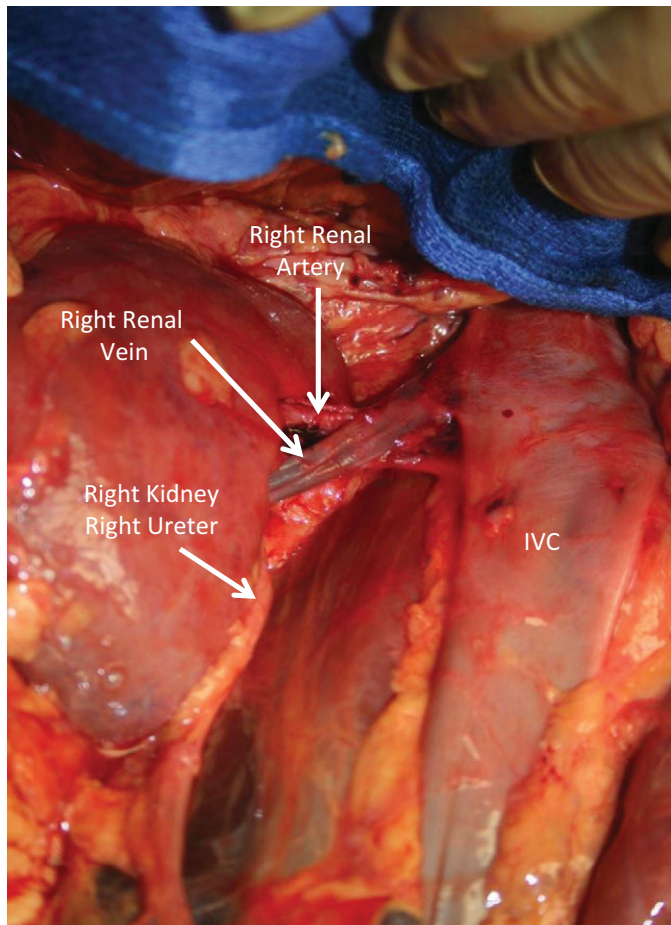


Figure 31.15 After right medial visceral rotation, the right renal hilum is identified. The IVC is exposed. Note the position of the right renal artery, posterior to the right renal vein and to the IVC. The right ureter is demonstrated posterior to the hilar vessels.

- An alternative approach to the exposure and proximal control of the renal arteries is through a midline retroperitoneal exploration. The transverse colon is retracted anteriorly and cephalad, placing the transverse mesocolon under tension. The ligament of Treitz is divided and the duodenum is retracted caudad and to the right. The left renal vein is identified and mobilized as needed to expose the origins of bilateral renal arteries.

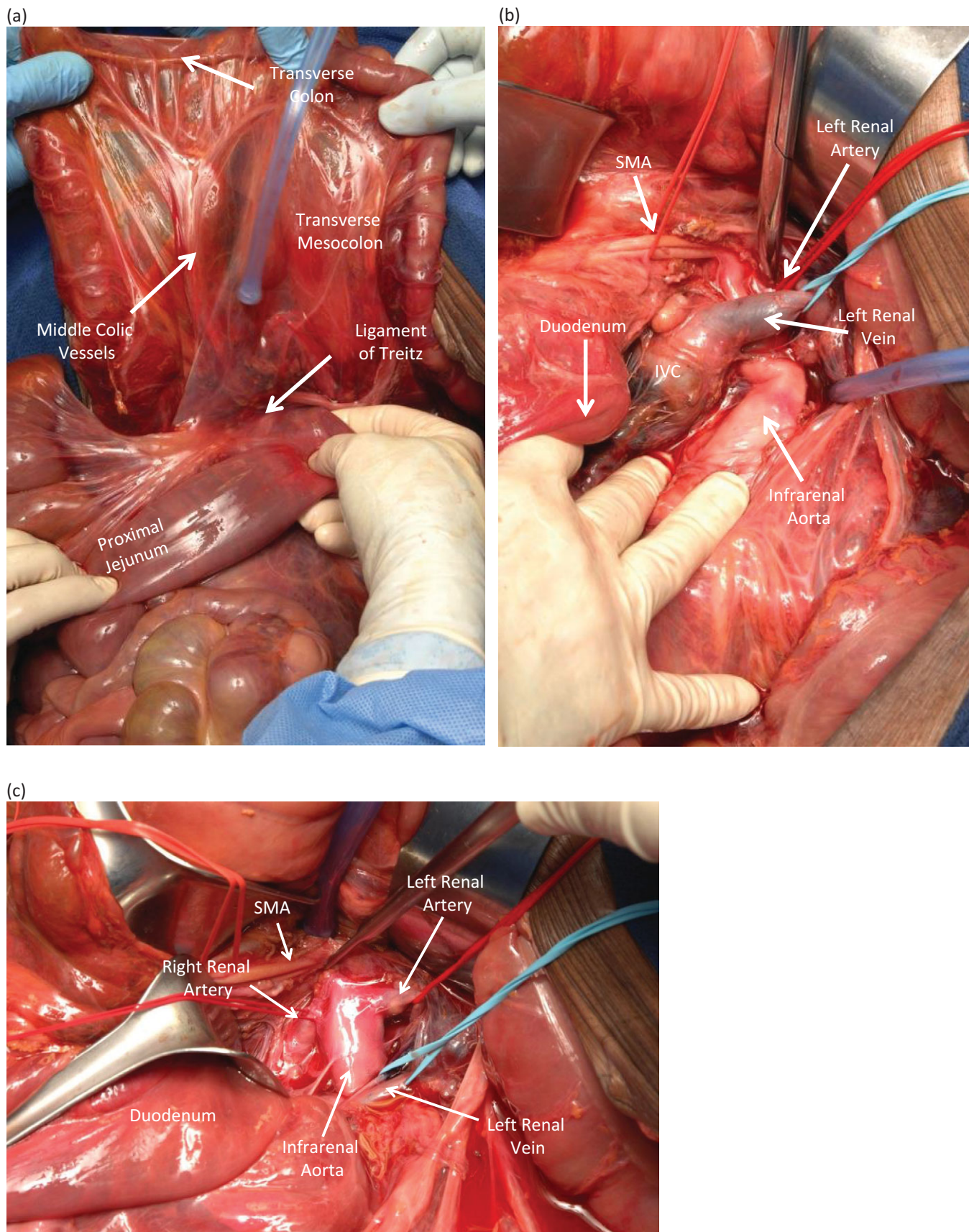


Figure 31.16 (a) Transverse colon is retracted anteriorly and cephalad, placing the transverse mesocolon under tension, exposing the fourth portion of the duodenum and the ligament of Treitz. (b) Midline retroperitoneal exploration after the ligament of Treitz had been divided and the duodenum retracted caudad and to the right. Note the left renal vein crossing over anteriorly to the aorta. Mobilization of the left renal vein provides access to the origin of bilateral renal arteries. (c) Through a midline retroperitoneal exploration, the left renal vein has been retracted caudad and the origin of both renal arteries is noted. Note the close proximity between the origins of the SMA and the renal arteries.

Inferior Mesenteric Artery

- Injury to the inferior mesenteric artery is managed by ligation with little risk of colonic ischemia.

Tips and Pitfalls

- In patients with suspected abdominal vascular injuries, where the IVC or iliac veins may be injured, the common femoral veins should not be used for venous access.
- In a young trauma patient, a small and constricted aorta may be difficult to identify within a large retroperitoneal hematoma. Likewise the choice of conduit size for reconstruction should take this acute vasoconstriction into account.
- During control of the aorta at the aortic hiatus, the esophagus should be carefully retracted to the patient's left to avoid inadvertent injury during application of the vascular clamp.
- Division of the left crus of the diaphragm for exposure of the distal thoracic aorta should be performed at 2 o'clock to avoid the inferior phrenic artery.
- During left medial visceral rotation, complete division of the splenic attachments to the diaphragm and careful mobilization of the spleen decreases the chance of capsular avulsion and bleeding, which may result in iatrogenic splenectomy.
- In order to obtain increased exposure to the pararenal aorta and renal arteries, the inferior mesenteric vein can be ligated without sequelae.

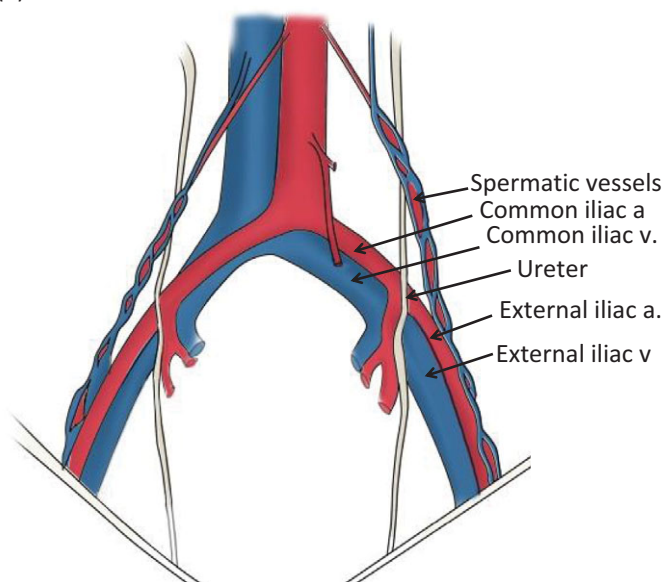
Iliac Vessel Injuries

Demetrios Demetriades and Kelly Vogt

Anatomy of the Iliac Vessels

- The abdominal aorta bifurcates into the two common iliac arteries at the level of the fourth to fifth lumbar vertebrae (surface landmark is the umbilicus). The common iliac arteries are about 5–7 cm in length.
- At the level of the sacroiliac joint, the common iliac arteries bifurcate to the external and the internal iliac arteries.
- The external iliac artery runs along the medial border of the psoas muscle and goes underneath the inguinal ligament to become the common femoral artery. It gives two major branches: the inferior epigastric artery, just above the inguinal ligament, and the deep iliac circumflex artery, which arises from the lateral aspect of the external iliac artery opposite the inferior epigastric artery.
- The internal iliac artery is a short and thick vessel, about 3–4 cm in length. It divides into the anterior and posterior branches at the sciatic foramen. These branches provide blood supply to the pelvic viscera, perineum, pelvic wall, and the buttocks.
- The ureter crosses over the bifurcation of the common iliac artery.
- The common iliac veins lie medially and posterior to the common iliac arteries. They join to form the inferior vena cava at the level of the fifth lumbar vertebra, posterior to the right common iliac artery.

(a)



(b)

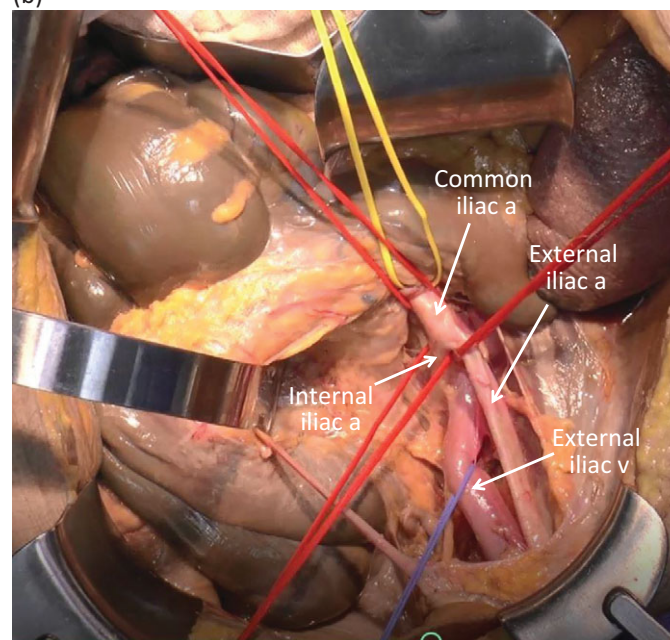


Figure 32.1 (a) Schematic anatomy of the iliac arteries, veins, and ureter crossing over the common iliac bifurcation. The external iliac veins run medial and posterior to the external iliac arteries. (b) Anatomy of the left iliac vessels. The common and external iliac veins run medial and posterior to the arteries.

General Principles

- For effective control of the bleeding from the iliac arteries, the internal iliac artery should always be included because bleeding may persist despite proximal and distal clamping of the vessels.
- Control of any enteric injuries and removal of enteric spillage should be done before definitive vascular reconstruction.
- The presence of enteric contamination is not a contraindication for the use of synthetic grafts and there is no need for routine extraanatomical bypass procedures. Copious irrigation and washout of the peritoneal cavity before arterial reconstruction and tissue coverage with adjacent peritoneum or omentum reduces the risk of graft infection.
- Extraanatomical bypass procedures are rarely indicated at the acute stage. They should be considered only in patients with graft infection.
- Ligation of the common or external iliac arteries should never be done because of the high incidence of limb loss and systemic complications. In patients “in extremis,” a damage control procedure with a temporary shunt should be considered.
- The internal iliac artery can be ligated with impunity.
- Ligation of the common or external iliac veins is usually tolerated well. In most patients, there is transient leg edema, which resolves with elevation and elastic stockings. In rare cases, there is development of extremity compartment syndrome requiring fasciotomy.
- Following arterial or venous injuries, the patient should always be monitored for extremity compartment syndrome. The combination of arterial and venous injuries is associated with a high risk of compartment syndrome, and these patients should be monitored closely. If continuous monitoring is not possible, liberal fasciotomy should be considered.
- Venous repairs producing more than 50% are associated with a high incidence of pulmonary embolism. In these cases, consider ligation or a vena cava filter.

Special Surgical Instruments

- The surgeon should have available a complete vascular tray, along with a laparotomy tray.
- If possible, operations should be performed in a suite with angiographic capabilities.
- A good headlight and magnifying loupes are strongly recommended!

Positioning

- The patient should be supine on the operating table, prepped to include access to the lower extremities.

Incisions

- The majority of injuries can be adequately managed using an extended midline laparotomy incision.
- If the exposure of the distal external iliac vessels is difficult, extension of the midline incision by adding a transverse lower abdominal incision or longitudinal incision over the groin and division of the inguinal ligament may be necessary.

Operative Technique

- The usual operative finding in iliac vascular injuries is severe intraperitoneal bleeding or a large retroperitoneal hematoma, or a combination of the two.
- Although proximal and distal control is desirable, in the presence of severe bleeding, direct entry into the hematoma with exposure and compression control is often faster and more effective. Although exposure of the vessels may be achieved through a peritoneal incision over the distal aorta and the iliac vessels, a medial rotation of the cecum and ascending colon on the right or the sigmoid and descending colon on the left, provide a better exposure of the vessels and the ureters. The small bowel is rotated cephalad and to the opposite site of the vascular injury and held in place with warm, wet sponges. The paracolic peritoneal reflexion is incised and the cecum or sigmoid is mobilized medially. The bleeding is controlled by direct pressure, and proximal and distal control is achieved with vascular clamps or vessel loops.

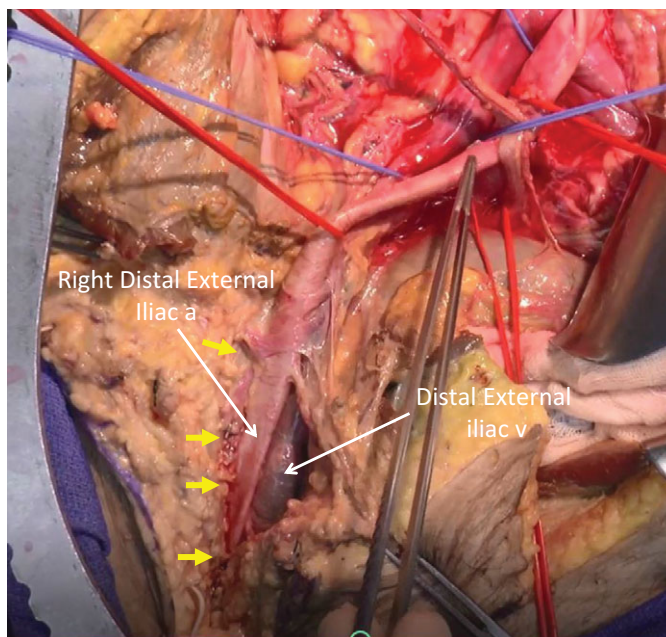


Figure 32.2 Extension of the midline incision by adding a transverse lower abdominal incision or longitudinal incision (yellow arrows) over the groin provides good exposure to the distal external iliac vessels.

- The ureter crosses over the bifurcation of the common iliac artery and should be gently retracted with a vessel loop and protected from accidental injury.
- Exposure of the iliac veins is technically more challenging than the iliac arteries because of their position underneath the arteries, especially on the right side. Some authors even recommend transection of the artery in order to gain adequate access to the underlying vein. This approach is not recommended, especially in a critically injured and coagulopathic patient! Adequate venous exposure can be achieved with mobilization of the artery and gentle traction with vessel loops. Ligation and division of the internal iliac artery provides additional mobilization and better venous exposure.
- Small arterial injuries without significant tissue loss may be repaired with adequate mobilization of the vessel and primary suturing. However, in most cases, a more complex reconstruction with a size 6–8 synthetic graft is necessary. Due to size mismatch, it is rarely possible to use saphenous vein autologous graft.
- Iliac artery transposition may be a reconstruction option in selected stable patients. The procedure involves ligation of the proximal common iliac artery near the aortic bifurcation. The distal external and internal iliac arteries are mobilized to allow for adequate length. The contralateral common and external iliac arteries are exposed. The injured artery is then anastomosed end to side to the contralateral common or external iliac artery (depending on anatomy), using a running 5-0 monofilament nonabsorbable suture.
- In patients in extremis, consider early damage control with temporary shunting. Semi-elective definitive reconstruction is performed after patient stabilization.
- Venous repair with lateral venorrhaphy should be considered in small injuries, which can be repaired without producing significant stenosis (<50% of the lumen). In most cases, the vein can safely be ligated. These patients should be monitored closely for extremity compartment syndrome. In rare cases, with post-ligation massive edema of the leg, reconstruction with ring graft may be necessary.
- The management of iliac venous injuries in the presence of associated iliac artery injuries is controversial. Some authors recommend venous reconstruction with patch venoplasty or PTFE grafts, although there is no evidence of improved outcome with this approach. Most surgeons do not recommend complex venous reconstructions because these patients are often in extremis and any procedures which prolong the operation may be counterproductive.
- The best damage control option is temporary shunting. Ligation of the common or external iliac artery should be avoided whenever possible to prevent irreversible limb ischemia

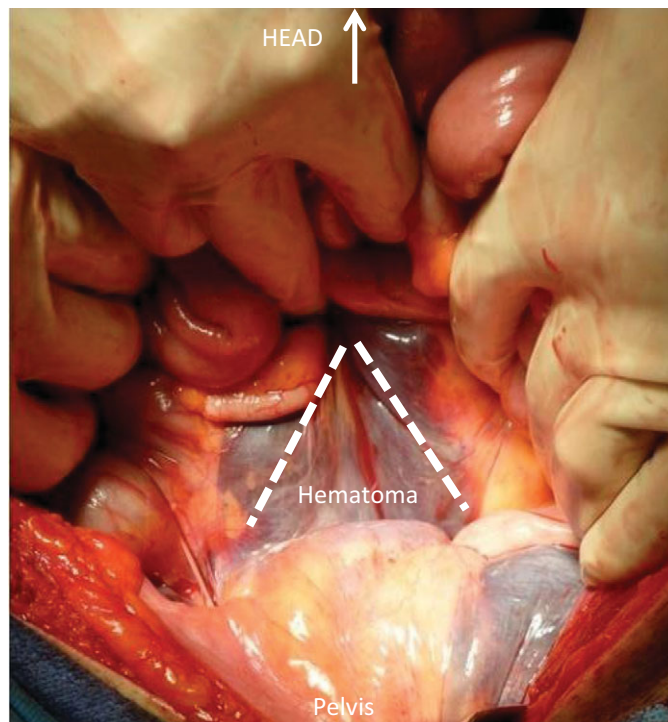


Figure 32.3 Retraction of the bowel cephalad and exposure of the retroperitoneum with underlying hematoma, secondary to iliac vascular injury. The vessels can be exposed with an incision on the peritoneum, directly over the vessels (dashed lines) or by medial rotation of the left or right colon.

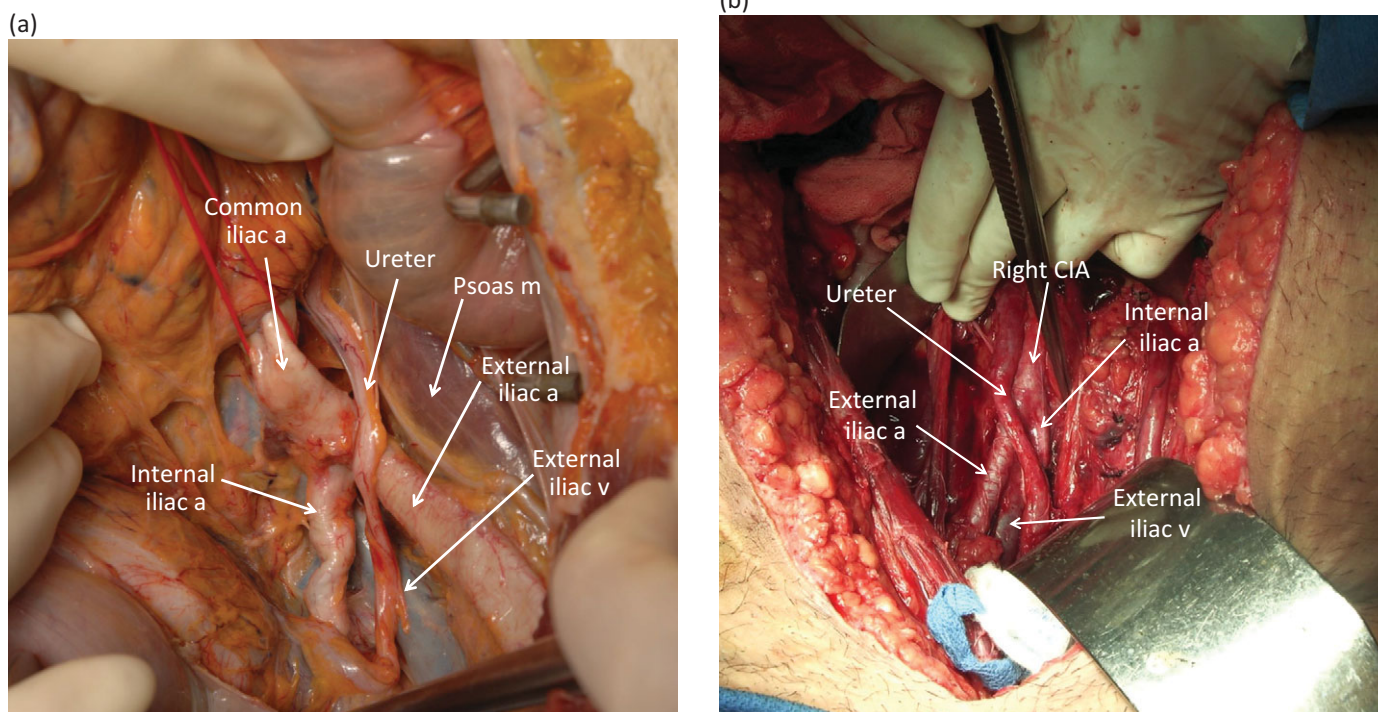


Figure 32.4 (a) Exposure of the left iliac vessels after medial rotation of the sigmoid colon. The external iliac vein is seen posteromedial to the artery. The ureter crosses over the bifurcation of the common iliac artery to the internal and external iliac arteries. (b) Exposure of the right iliac vessels after medial rotation of the right colon. Note the external iliac vein running posteromedial to the artery. The ureter crosses over the bifurcation of the common iliac artery.

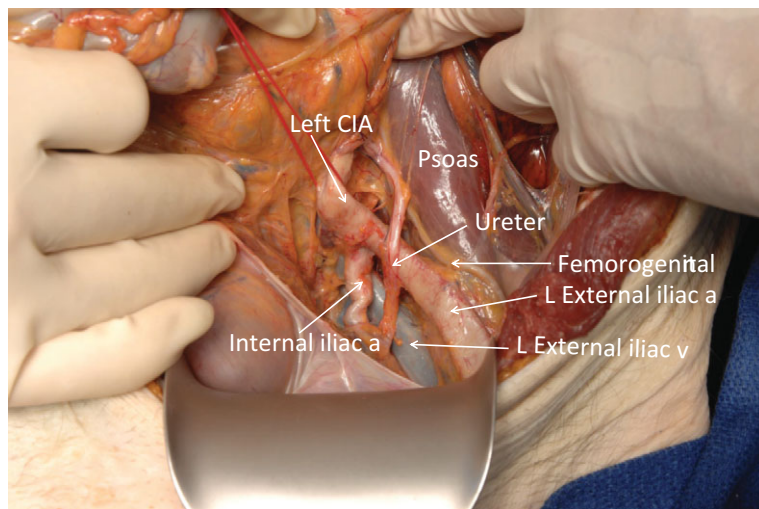


Figure 32.5 Left common iliac artery branching to external and internal iliac arteries. The external iliac vein is identified medial and posterior to the artery.

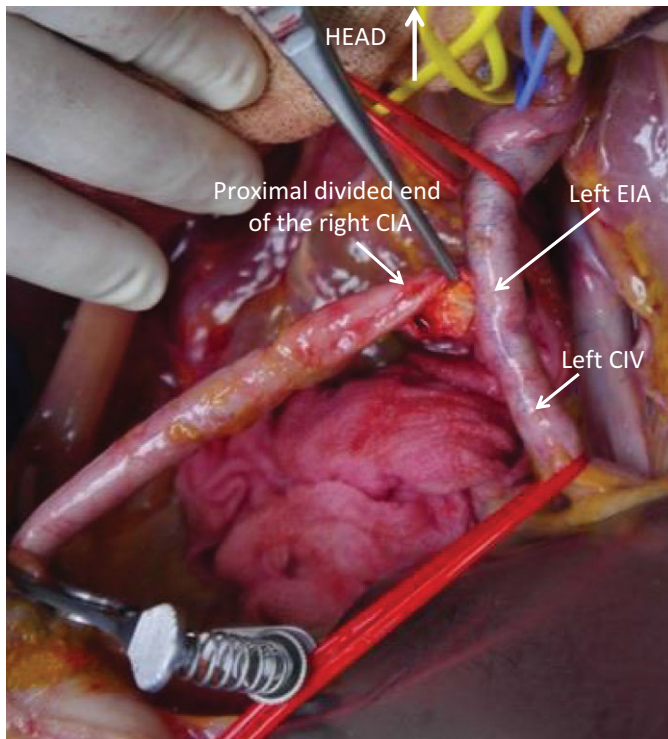


Figure 32.6 The right common iliac artery after transection and set up for transposition to the left common iliac artery.

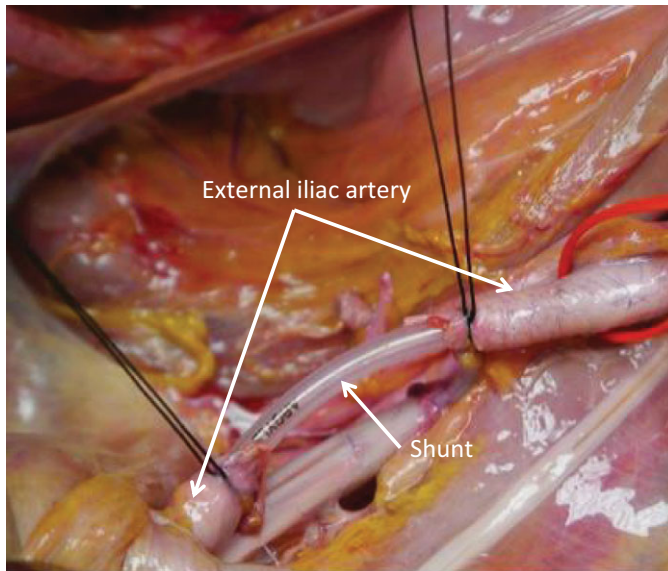


Figure 32.7 External iliac artery injury with temporary shunt in place.

Tips and Pitfalls

- When clamping or mobilizing the iliac artery, proceed cautiously to avoid iatrogenic injury to the underlying vein.
- The ureter crosses over the bifurcation of the common iliac artery and is at risk of iatrogenic injury. Retract it out of the way with a vessel loop.
- Exposure of the iliac veins is more difficult than exposure of the arteries because of their anatomic position. Good mobilization of the artery and retraction with vessel loops allows venous exposure. Ligation and division of the internal iliac artery improves the exposure. Avoid the recommendation by some authors to divide the common or external iliac artery in order to improve the exposure of the underlying vein.
- Extraanatomical bypass (axillofemoral or femorofemoral) is rarely indicated at the acute stage. Its main indication is in patients with postoperative graft infection.
- If repair of the iliac vein produces significant stenosis, consider anticoagulation and inferior vena cava filter placement to prevent pulmonary embolism.
- Some patients with iliac vascular injuries (especially in combined arterial and venous injuries or prolonged ischemia) develop extremity compartment syndrome. In these cases, a therapeutic fasciotomy should be performed without delay, often before arterial reconstruction.
- The role of prophylactic fasciotomy is controversial and has been challenged by many authors. If it is elected not to perform a fasciotomy, the patient should be monitored closely with frequent clinical examinations, serial CPK levels, and, in the appropriate cases, with compartment pressure measurements. Fasciotomy should be performed at the first signs of compartment syndrome. More liberal prophylactic fasciotomy should be considered if continuous monitoring is not possible.

Inferior Vena Cava

Lydia Lam, Matthew D. Tadlock, and Demetrios Demetriades

Surgical Anatomy

- The inferior vena cava (IVC) is formed by the confluence of the common iliac veins, just anterior to the L5 vertebral body, and posterior to the right common iliac artery. As it courses superiorly towards the diaphragm, it lies to the right of the lumbar and thoracic vertebral bodies. It enters the thorax at T8, where the right crus of the diaphragm separates the IVC and aorta. In most individuals, there is a small segment of suprahepatic IVC, about 1 cm in length, between the liver and diaphragm, which is amenable to cross clamping.
- The IVC receives four or five pairs of lumbar veins, the right gonadal vein, the renal veins, the right adrenal vein, the hepatic veins, and the phrenic veins. It is of practical importance to remember that all lumbar veins are below the renal veins and that between the renal veins and the hepatic veins, besides the right adrenal vein, there are no other venous branches. The left lumbar veins pass behind the abdominal aorta.

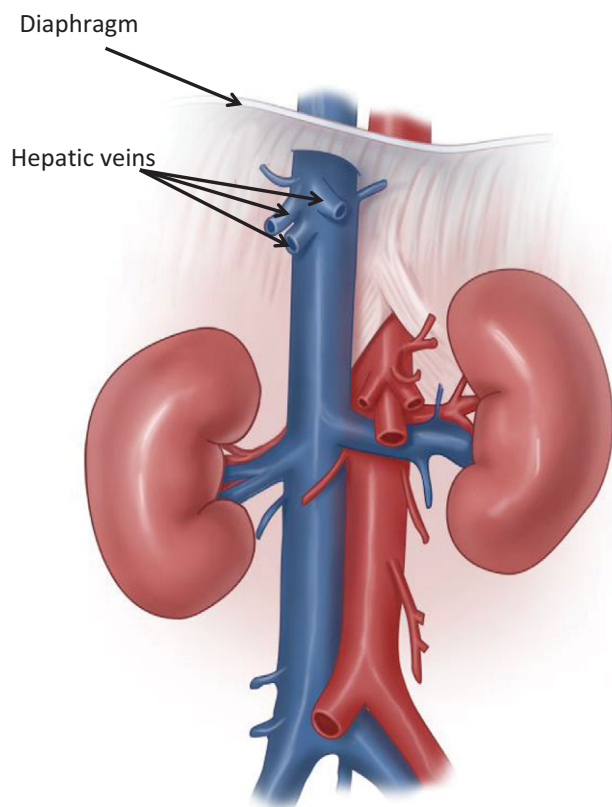


Figure 33.1 Anatomy of the inferior vena cava (IVC). Note the right renal artery coursing behind the IVC.

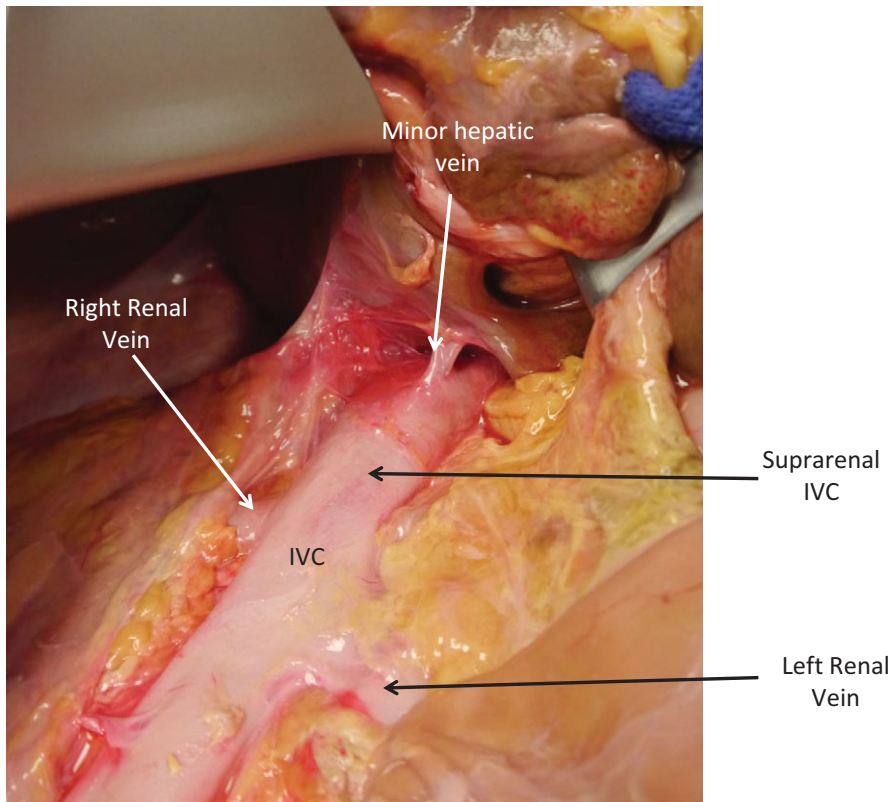


Figure 33.2 The suprarenal IVC has no lumbar veins and thus poor collaterals. Ligation of the IVC in this location leads to renal failure.

- The confluence of the renal veins with the IVC lies posterior to the duodenum and the head of the pancreas.
- The retrohepatic IVC is about 8–10 cm in length and is adhered to the posterior liver, helping to anchor the liver in place. In this liver “tunnel,” several accessory veins from the caudate lobe and right lobe drain directly into the IVC.
- There are three major hepatic veins which drain the liver into the IVC. The extrahepatic portion of these veins is short, measuring about 0.5–1.5 cm in length. The right hepatic vein is the largest. In about 70% of individuals, the middle vein drains into the left hepatic vein to enter the IVC as a single vein.
- The thoracic IVC is almost entirely in the pericardium.
- During induction of anesthesia in patients with severe intra-abdominal bleeding, there is a high risk of rapid hemodynamic decompensation or even cardiac arrest. The surgical team should be ready and the skin preparation should be performed before induction of anesthesia.
- During exploration of a caval injury, there is high risk for air embolism. Prevent this complication by early direct compression, followed by proximal and distal control.
- Because of the extensive collateral circulation below the renal veins, the infrarenal cava can be safely ligated with acceptable morbidity of lower extremity swelling that is usually temporary.
- Following IVC ligation, the lower extremities and feet should be wrapped with elastic bandages to reduce edema. Monitor closely for extremity compartment syndrome.
- Following packing or repair of IVC injuries, the patient should not be over-resuscitated.

General Principles

- The IVC is the most frequently injured abdominal vessel, following penetrating trauma. Blunt trauma to the IVC usually involves the retrohepatic part of the vein.
- Patients with intra-abdominal IVC injury, who present to the hospital alive, typically have a contained retroperitoneal hematoma and, therefore, may initially appear to be hemodynamically stable.
- Avoid femoral vein catheters in patients with penetrating abdominal trauma because of the possibility of proximal iliac or IVC injury.
- In abdominal gunshot wounds, obtain a plain abdominal radiograph prior to going to the operating room if time permits, as it helps determine missile trajectory and other structures at risk.

Special Surgical Instruments

- In addition to a standard trauma laparotomy instrument tray, vascular clamps with multiple lengths and angulations must be available.
- A self-retaining retractor, such as Omni-Tract or Bookwalter.
- A sternotomy set should be available in case a median sternotomy is needed for improved exposure of the retrohepatic IVC.
- Surgical headlamp is important.

Patient Positioning

- Supine, with upper extremities abducted to 90°. Skin antiseptic preparation should include the chest, abdomen, and groins.
- Use upper and lower body warming devices.

Incisions

- Extended midline trauma laparotomy from xiphoid to pubic symphysis.
- The laparotomy may be extended through a subcostal incision to provide exposure to the retrohepatic IVC (see [Chapter 22 General Principles of Abdominal Operations for Trauma](#))



Figure 33.3 (a) Addition of a right subcostal incision to the standard midline laparotomy improves the exposure of the retrohepatic veins. The subcostal incision is made 1–2 fingerbreadths below the costal margin. Avoid an acute angle between the two incisions to prevent ischemic necrosis of the skin. **(b)** A median sternotomy may be added to the midline laparotomy in cases requiring access to the intrapericardial segment of the inferior vena cava for vascular occlusion of the liver, or to the heart for placement of an atriocaval shunt.



Exposure

- In penetrating trauma, upon entering the peritoneal cavity, the usual findings include a large retroperitoneal hematoma with or without free intraperitoneal bleeding. In blunt trauma, the most likely finding is a retroperitoneal hematoma, usually retrohepatic.
- Almost all retroperitoneal hematomas due to penetrating trauma should be explored, irrespective of size, to rule out an underlying vascular or hollow viscus injury. The only exception is a stable and nonexpanding retrohepatic hematoma. Surgical exploration of the retrohepatic vena cava or the hepatic veins is difficult and potentially dangerous.
- Retroperitoneal hematomas due to blunt trauma rarely require exploration. However, paraduodenal hematomas or any large, expanding or leaking hematomas should be explored.
- The infrarenal and juxtarenal IVC is best exposed by mobilization and medial rotation of the right colon, the hepatic flexion of the colon, and the duodenum.
- The small bowel is eviscerated to the left of the patient and kept in place with warm and moist towels. The avascular white line of Toldt, lateral to the colon, is divided, using sharp dissection or electrocautery. The cecum, right colon, and hepatic flexure are mobilized and retracted medially.

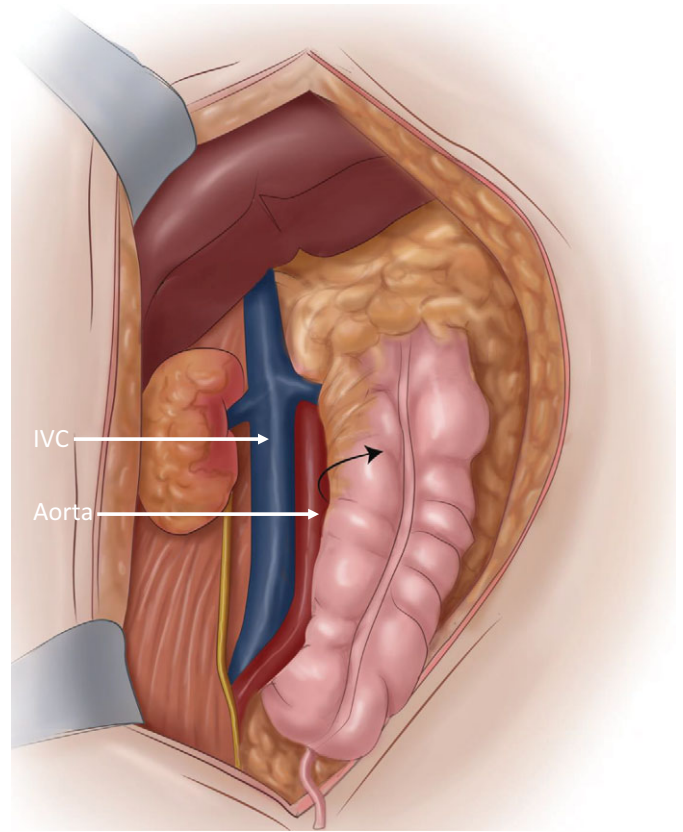


Figure 33.4 Medial rotation of the right colon combined with Kocher mobilization of the duodenum provides good exposure of the inferior vena cava, the right renal vessels, and the right iliac vessels.

- Following the medial visceral rotation, the second portion of the duodenum, the Gerota's fascia of the right kidney, and the iliopsoas muscle are exposed.
- The duodenum is then mobilized medially with the Kocher maneuver by incising the lateral peritoneal attachments of the first, second, and proximal third portions of the

duodenum. The C-loop of the duodenum and the pancreatic head are retracted medially to expose the inferior vena cava posteriorly.

- The IVC is then visualized with the aorta to the left of IVC. The paired renal veins and the right gonadal vein are visualized draining into the IVC.

(a)

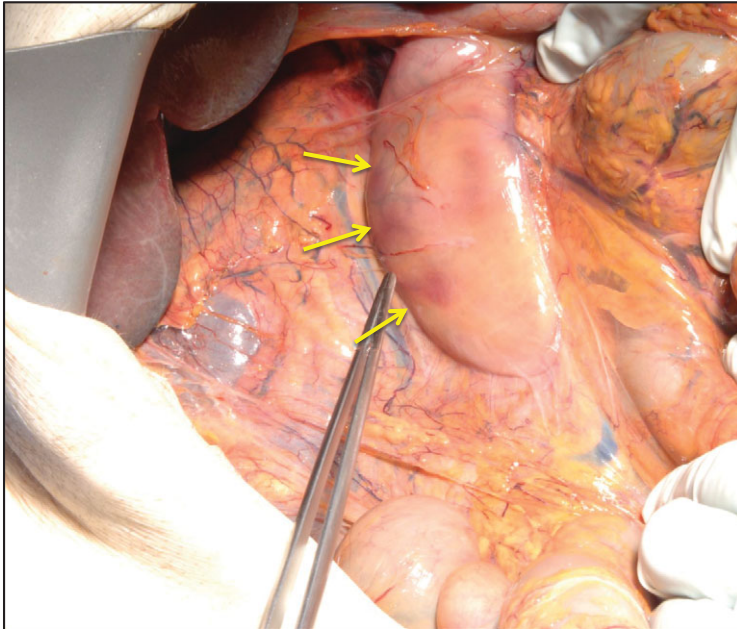
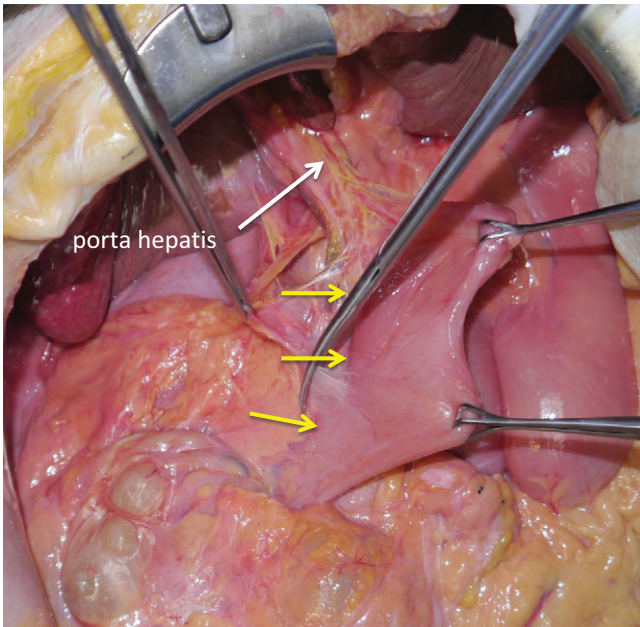
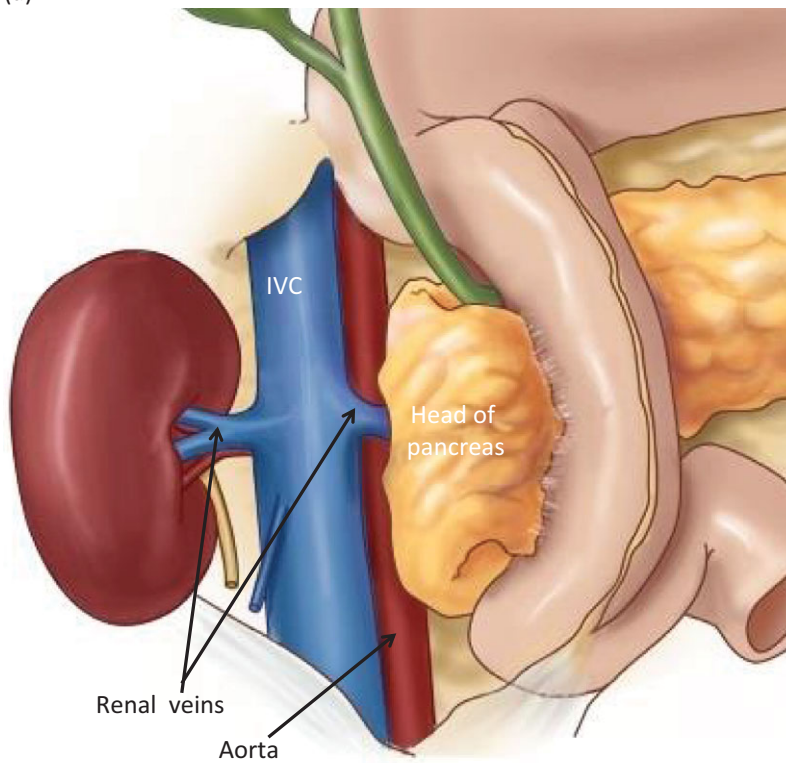


Figure 33.5 (a, b) Kocher Maneuver: The lateral attachments of the duodenum (yellow arrows) are sharply divided, exposing the lateral and posterior surfaces of the second portion of the duodenum.

(b)



(a)



(b)

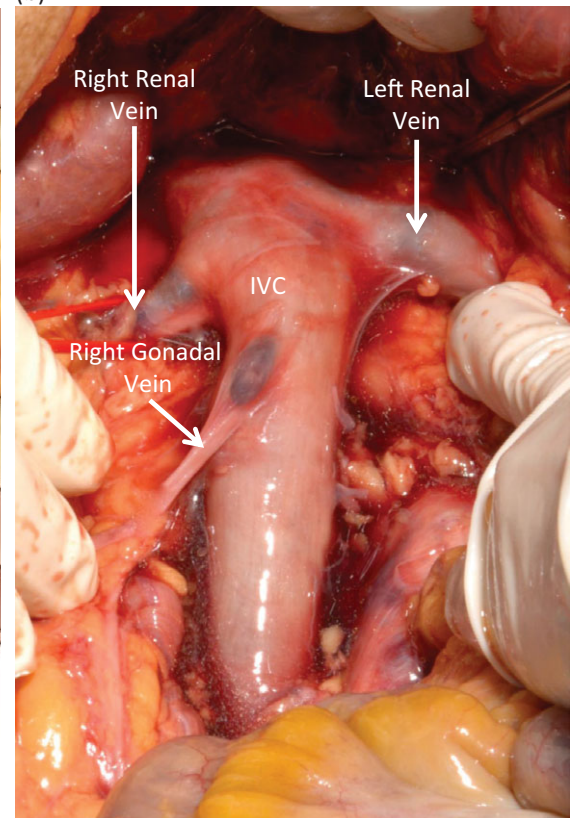


Figure 33.6 (a) Kocher maneuver with medial mobilization of the duodenum exposes the juxtarenal inferior vena cava and the renal veins. (b) Exposure of the juxtarenal IVC, after Kocher maneuver and medial visceral rotation.

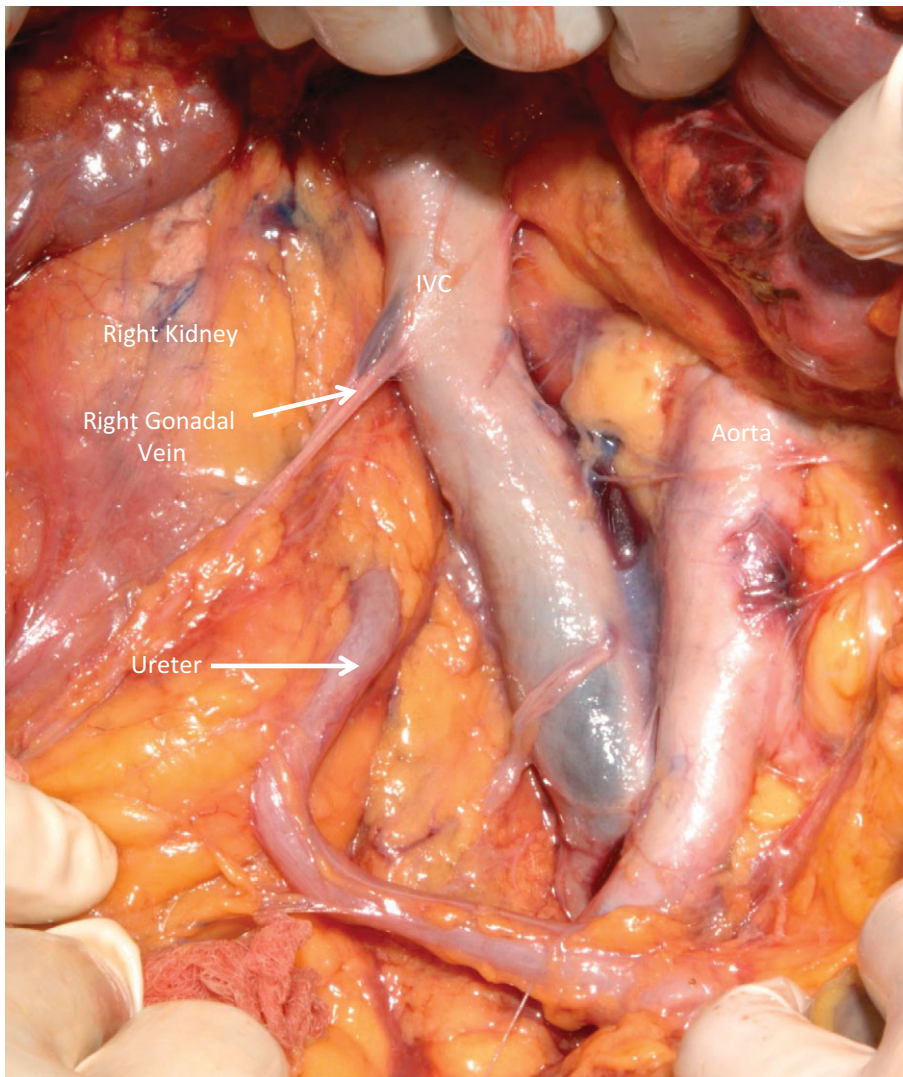


Figure 33.7 Exposure of the infrahepatic IVC after medial visceral rotation and Kocher mobilization of the duodenum.

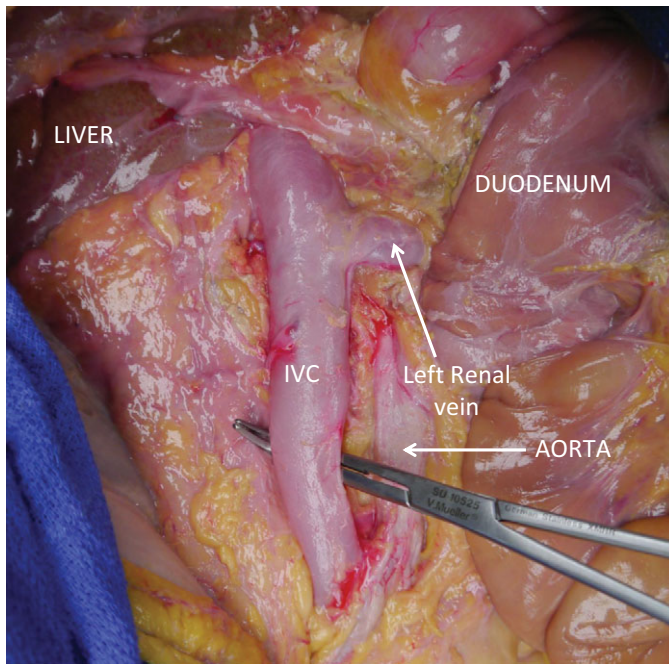


Figure 33.8 Control of the IVC can be achieved by encircling it, being careful not to avulse any of the lumbar veins. Taking a medial to lateral approach will ensure no injury to the aorta.

- Circumferential infrarenal IVC control may be necessary. The IVC should be carefully encircled with a right angle, taking care to avoid injury to the lumbar veins.

Hemorrhage Control and Venous Repair

Suprarenal, Juxtarenal, and Infrarenal IVC

- In the unstable patient in extremis, aortic inflow control through the abdomen, just below the diaphragm ([Chapter 31](#)) may be necessary prior to IVC exposure.
- The initial hemorrhage control can be achieved by direct digital compression and subsequent application of a side vascular clamp, if possible. Alternatively, two sponge sticks are placed above and below the IVC injury, compressing the vein against the vertebral bodies. Ligation or clipping of some of the lumbar veins may be necessary for complete vascular control.
- Many IVC lacerations can be repaired primarily with a 4-0 or 5-0 nonabsorbable monofilament suture.

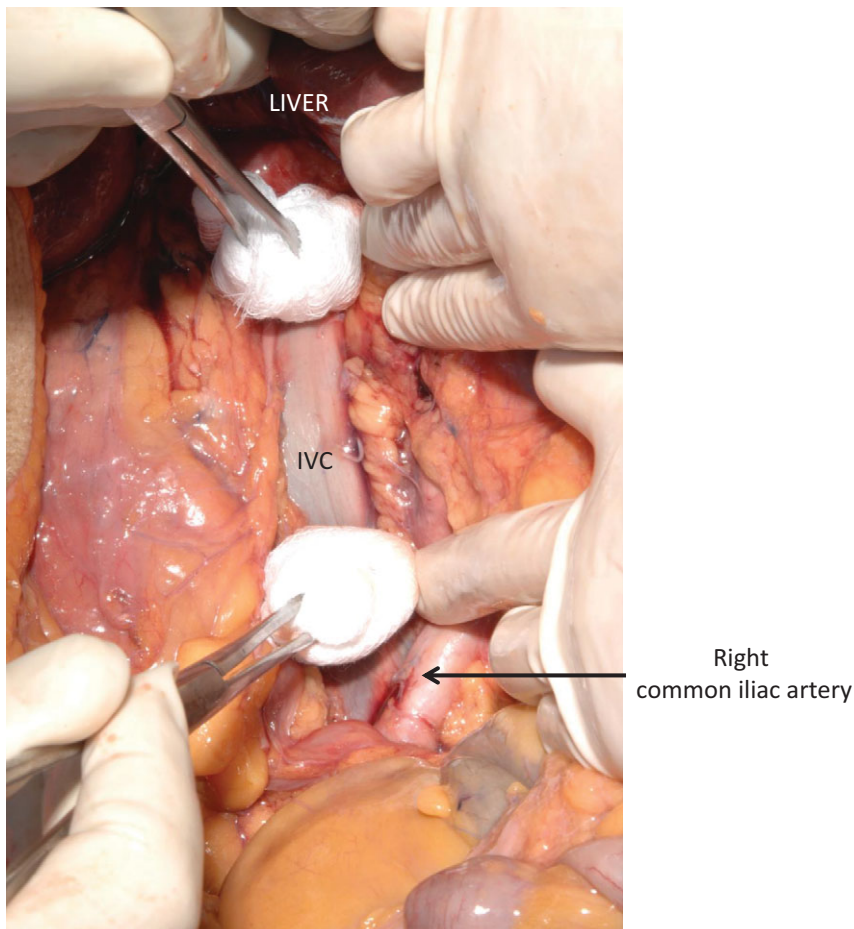
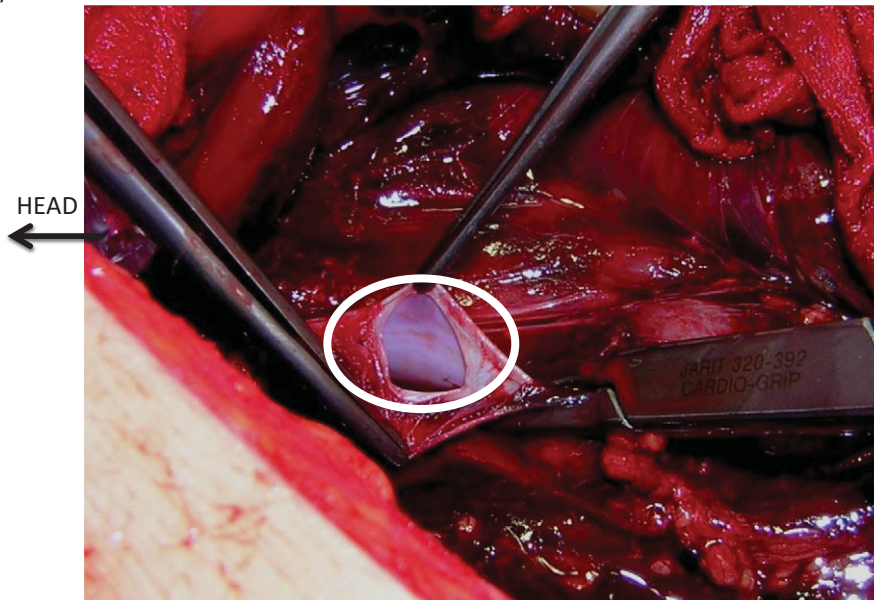


Figure 33.9 Temporary bleeding control and prevention of air embolus with compression with two sponge sticks above and below the IVC injury, compressing the vein against the spine.

(a)



(b)

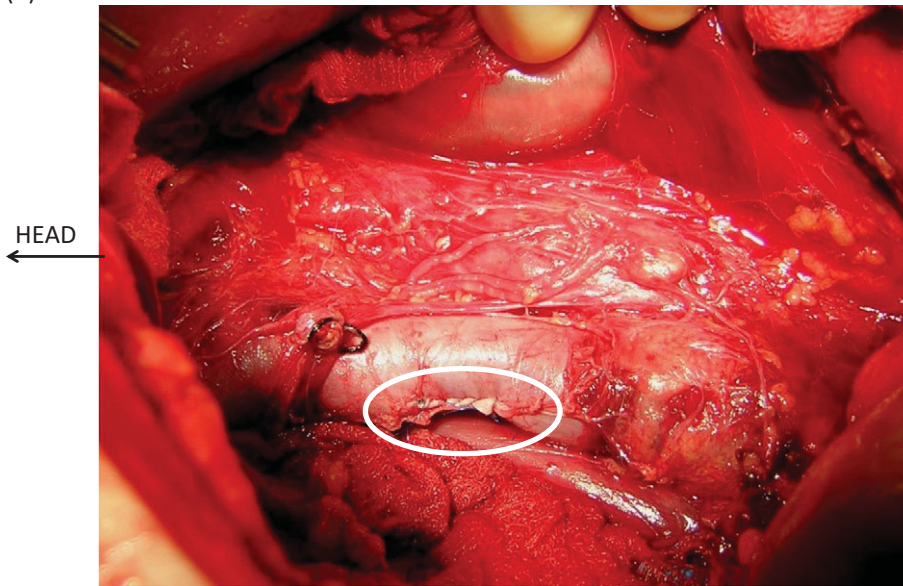
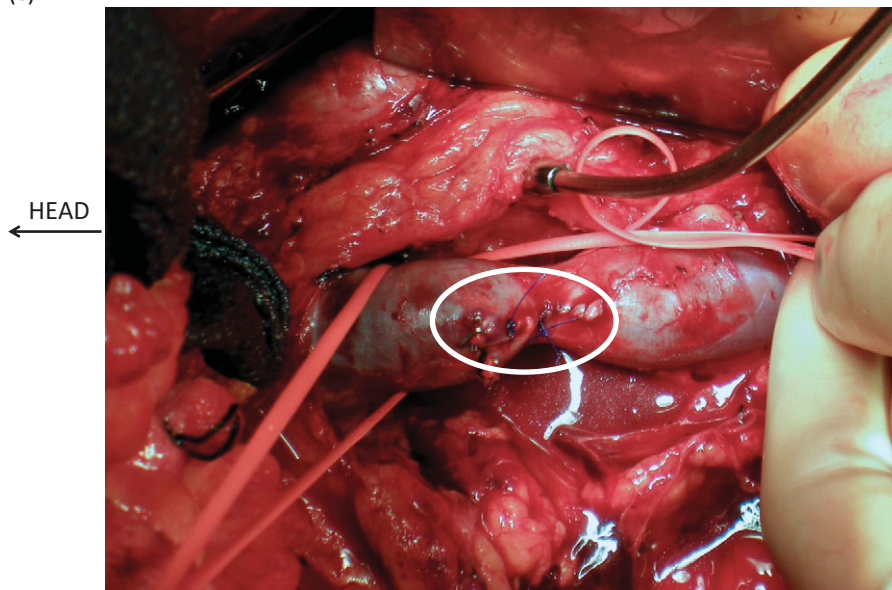


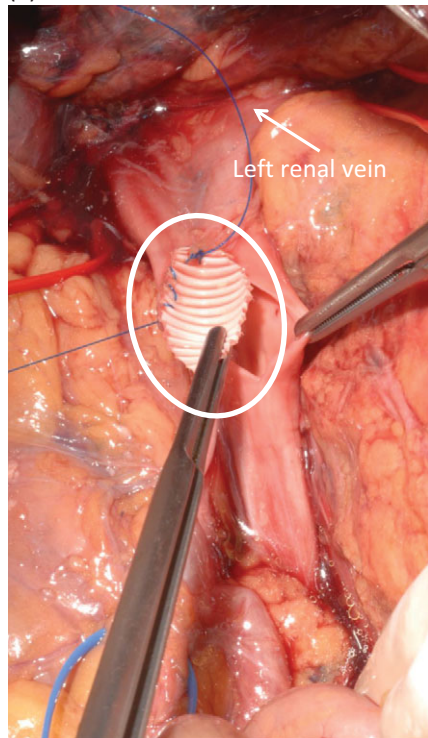
Figure 33.10 (a) Primary repair of the IVC with nonabsorbable 4-0 or 5-0 monofilament is usually possible in most knife wounds and some low-velocity gunshot wounds. (b) Primary repair of the IVC with no significant stenosis. (c) Primary repair of the IVC with significant stenosis. If the stenosis is >50% of the lumen, there is an increased risk of thrombosis and pulmonary embolism.

(c)

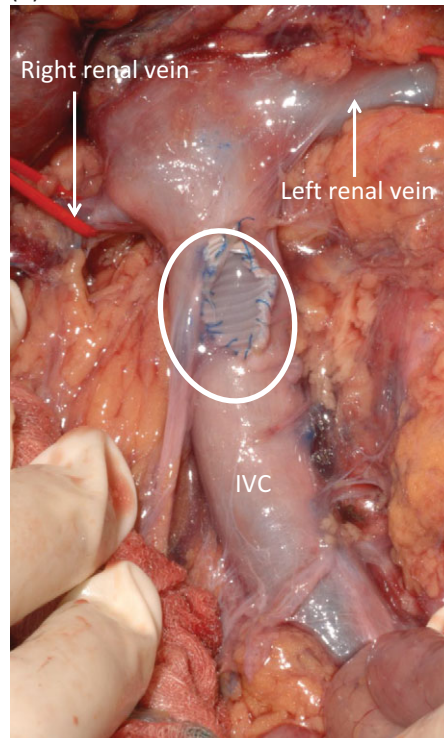
**Figure 33.10** (cont.)

- While some stenosis of the IVC after repair is of little consequence, more than 50% stenosis is associated with a significant risk of thromboembolism. In these cases, other options should be considered:
 - Repair of the IVC with an autologous venous or biologic or synthetic patch, sutured in place with 4-0 or 5-0 nonabsorbable monofilament suture.
 - Place a vena cava filter above the area of stenosis. This can be done intraoperatively with the application of a caval clip or postoperatively with the insertion of a caval filter.
 - Ligation of the infrarenal IVC should be considered in cases with extensive tissue loss or if the patient is “in extremis.”

(a)



(b)

**Figure 33.11 (a, b)** Synthetic or venous patches can be used to avoid >50% stenosis for repair of the IVC. The patch is sutured in using a 5-0 or 6-0 nonabsorbable monofilament suture.

- The graft or patch should be covered with any surrounding tissues or omentum to protect from infection or pancreatic leaks.
- Exposure of posterior IVC injuries can be achieved through circumferential mobilization of the IVC or within the lumen through an anterior venotomy.
 - Mobilize the IVC, rotate it medially, and repair the injury, being cautious of avulsing the lumbar veins.
- An anterior caval venotomy is another option to access a posterior injury. Once the posterior cava is repaired, the anterior injury can be repaired primarily or with a vascular patch depending on the degree of stenosis that results after primary repair.

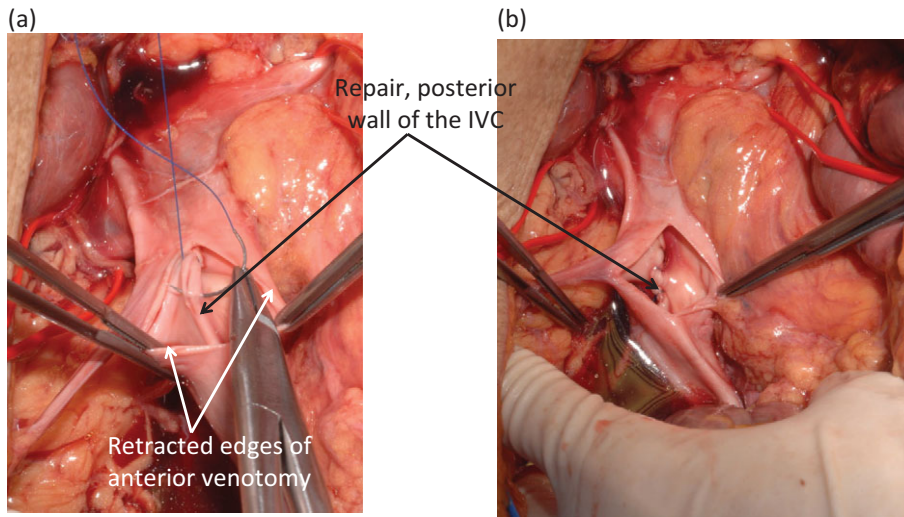


Figure 33.12 (a) Posterior IVC injury can be repaired through an anterior venotomy. The anterior venotomy is usually present in penetrating injuries and can easily be extended.

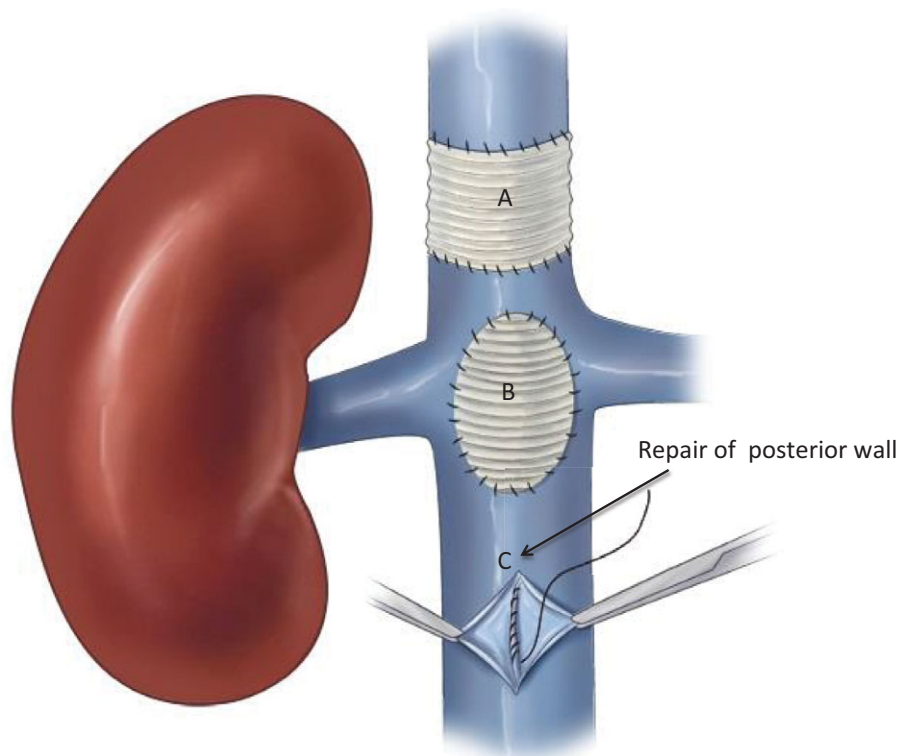


Figure 33.13 Methods of reconstruction in complex IVC injuries. Interposition synthetic graft (A), synthetic patch (B), Repair of posterior wall through anterior venotomy (C).

- Complete reconstruction of the IVC with a prosthetic interposition graft inserted to reestablish IVC continuity in selected cases involving the suprarenal IVC, which are not amenable to simpler repairs. The injured portion is resected and an end-to-end anastomosis to the IVC is performed with a ringed Dacron or PTFE graft.
 - For juxtarenal injuries, ligation of the right renal vein necessitates a right nephrectomy. The left renal vein can be ligated close to the IVC preserving the left gonadal vein, which provides adequate venous drainage.
- The suprarenal cava is a very short segment of IVC just below the liver and above the renal veins that is difficult to expose.
 - Repair should be attempted, if technically possible. The exposure of the laceration can be improved by applying Allis or Babcock traumatic clamps to control the bleeding and pull down suprarenal injuries, facilitating venorrhaphy.
 - In cases with significant tissue loss, a vascular patch can be placed. For complex injuries not amenable to simple venorrhaphy or a vascular patch, a synthetic interposition or native vein graft can be utilized.
- Ligation of the suprarenal cava should be avoided because it results in renal failure in all cases. However, in patients “in extremis,” it might be the only option.
- Damage control procedures should be considered in patients “in extremis” with severe coagulopathy, hemodynamic instability, or acidosis. They include:
 - Ligation of the infrarenal IVC.
 - Placement of a temporary shunt and semi-elective reconstruction at a later stage. A chest tube can be used, being mindful to include vents near the renal veins if the shunt traverses them. The shunt is secured with either vessel loops that are double looped and secured with clips or a braided suture anchoring the shunt in place.

Retrohepatic IVC

- A retrohepatic hematoma or bleeding is suggestive of an injury to the retrohepatic IVC or hepatic veins. Characteristically, the bleeding becomes worse when the liver is retracted anteriorly and the Pringle maneuver is not effective in controlling bleeding.
- Exposure of the retrohepatic hematomas is technically very difficult and should be avoided, if possible. If the

hematoma is not bleeding actively or not expanding, it should be left undisturbed. The liver ligaments should not be divided, in order to preserve the tamponade effect.

- If the retrohepatic bleeding can be controlled with gauze packing, this technique should be the treatment of choice and the operation should be terminated. The patient should be returned to the operating room for removal of the packing after complete physiological stabilization of the patient, usually 24–36 hours after the initial procedure. If after removal of the packs there is still bleeding, repacking should be done again.
- The effective packing of the retrohepatic bleeding requires posterior compression of the liver. The packs should be placed between the liver and the anterior abdominal wall and also under the inferior surface of the liver. This

packing compresses the liver posteriorly, against the IVC, and produces a more effective tamponade. No packs should be placed between the liver and IVC.

- If the perihepatic packing is not effective in controlling bleeding, exposure and repair of the venous bleeding remains the only option. The standard midline laparotomy alone does not provide appropriate exposure. Additional exposure through a subcostal incision, or a median sternotomy or a right thoracotomy, is needed for good visualization of the retrohepatic vessels.
- A subcostal incision is the most common option and provides good exposure to the posterior right lobe of the liver and the retrohepatic vessels. Division of the falciform and coronary ligaments should be performed to allow inferomedial rotation of the liver.

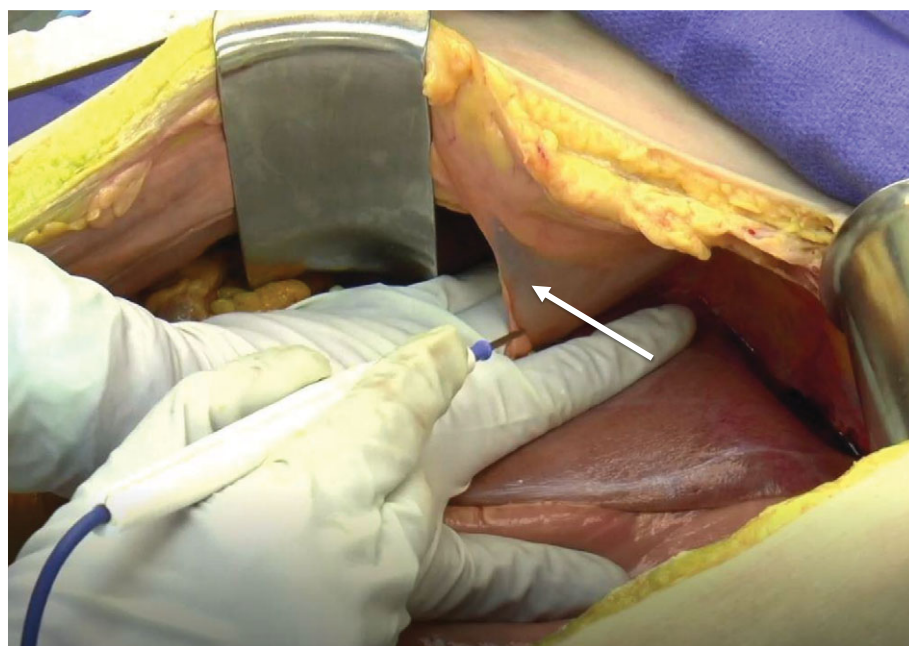


Figure 33.14 Division of the falciform ligament (arrow) allows inferomedial rotation of the liver and improved exposure of the retrohepatic veins.

- A right thoracotomy incision, through the 6–7 intercostal space to join up with the midline laparotomy incision, and division of the diaphragm straight down to the IVC diaphragmatic foramen, allows exposure of the entire length of the retrohepatic and suprahepatic IVC.
- Extension of the laparotomy incision into a median sternotomy should be done only if an atriocaval shunt is planned.
- Complete vascular control of the retrohepatic IVC requires many steps. The first step is infradiaphragmatic clamping of the aorta, followed by clamping of the portal triad (Pringle maneuver, for hepatic artery and portal vein control), the infrahepatic IVC, and the suprahepatic IVC.
- Aortic control should always be done first in order to reduce the risk of hypovolemic cardiac arrest. The technique is described in [Chapter 31](#) of Abdominal Aorta and Splanchnic Vessels

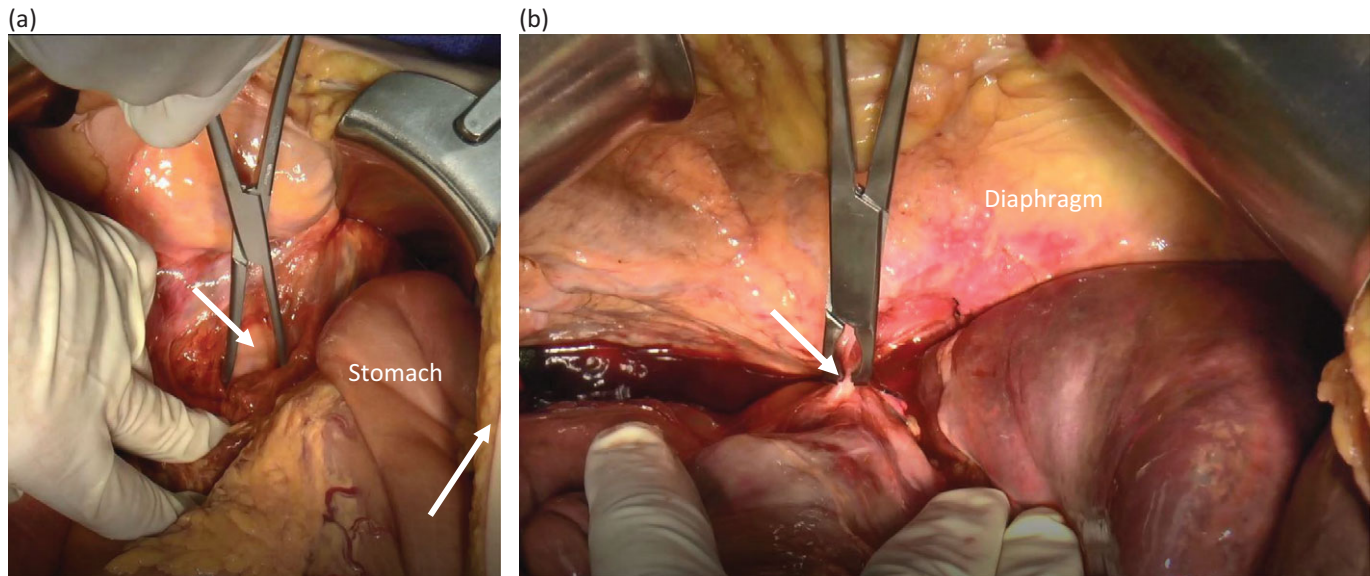


Figure 33.15 (a, b) Cross-clamping of the abdominal aorta (arrow), below the diaphragm. The avascular left crux of the diaphragm can be divided for better exposure.

- Suprahepatic IVC control can be achieved at two different locations.
- Between the liver and the diaphragm: In most individuals there is typically a 0.5–1.0 cm portion of the IVC, where a vascular clamp can be placed. Follow the

falciform ligament posteriorly until the hepatic veins and IVC are encountered and apply a vascular clamp.

In the pericardium: This approach requires the addition of a right thoracotomy or a median sternotomy, as described above.

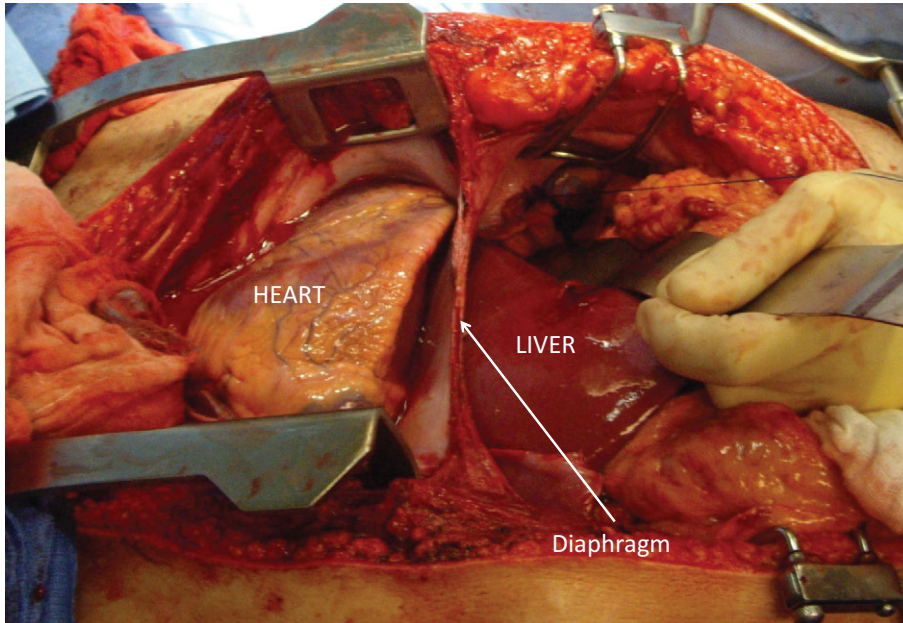


Figure 33.16 Exposure for placement of atriocaval shunt or supradiaphragmatic isolation of the IVC requires extension of the midline laparotomy into a median sternotomy.

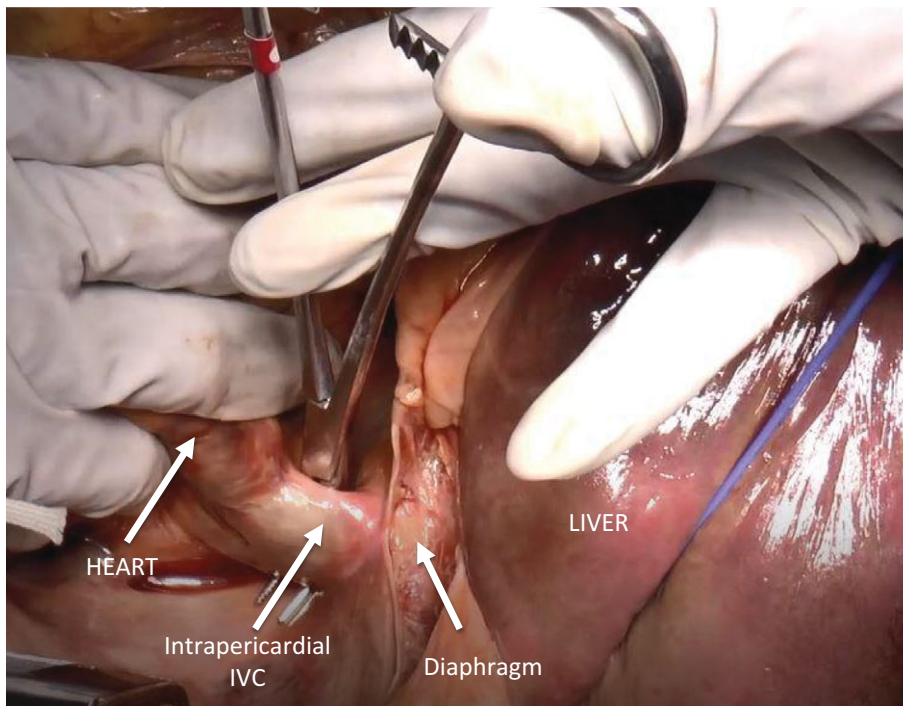


Figure 33.17 Combined laparotomy and median sternotomy. Isolation of the intrapericardial IVC in preparation for total liver vascular isolation.

- Infrahepatic IVC control is achieved by placing a suprararenal vascular clamp.
- The portal triad control or the Pringle maneuver is performed through the foramen of Winslow. The portal triad can be clamped or encircled with a vessel loop. (see [Chapter 27, Liver and Biliary Tract Injuries](#)).
- Exposure of the retrohepatic IVC is achieved by inferomedial rotation of the right lobe of the liver.

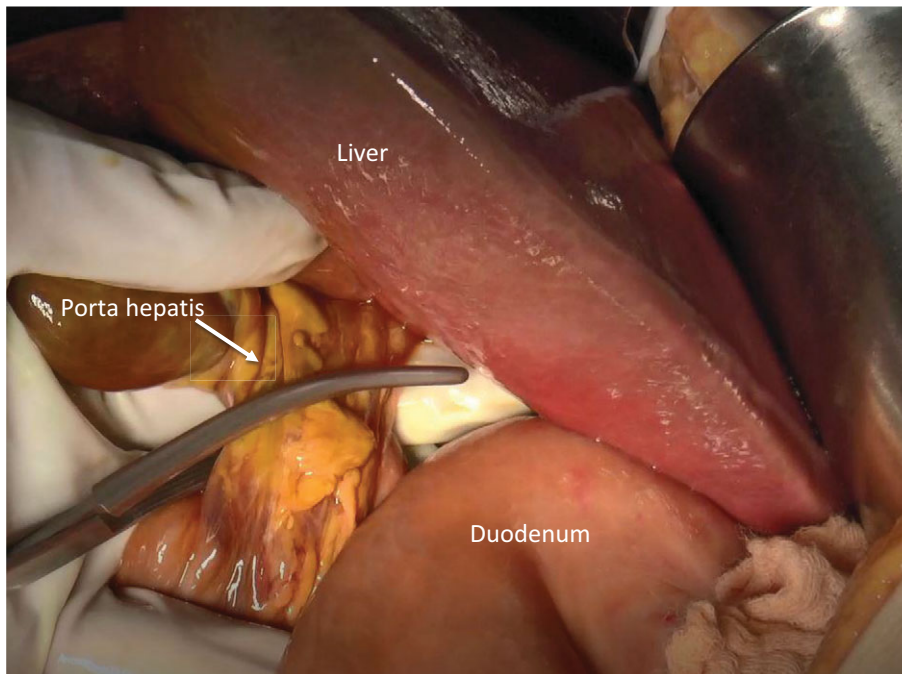


Figure 33.18 Pringle maneuver. A vascular clamp is applied through the foramen of Winslow on the porta hepatis.

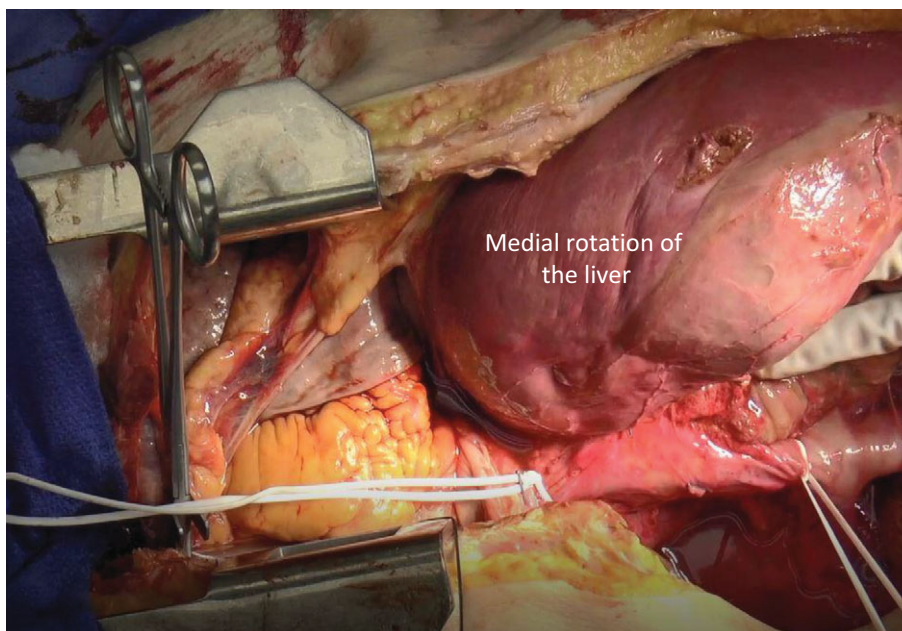


Figure 33.19 Exposure of the retrohepatic IVC. Following extension of the laparotomy into a median sternotomy or a right subcostal incision, the liver is rotated inferomedially and the IVC is exposed.

- In extreme situations, the retrohepatic IVC injury can be bypassed with the insertion of an atriocaval shunt.
 - The laparotomy incision is extended into a median sternotomy and the pericardium is opened.
 - A tape tourniquet is then applied around the intrapericardial IVC. The right atrial appendage is occluded with a vascular clamp and a 2-0 silk purse-string suture is placed in the appendage. A size-8 endotracheal tube, with a side hole cut at about 8–10 cm from the clamped proximal end of the tube, is then inserted through the purse-string. The tube is guided by the surgeon into the IVC, the balloon is inflated just above the renal veins, and the tape

tourniquet around the intrapericardial IVC is tightened.

- Alternatively, a size-36 chest tube, with cut fenestrations in its proximal part to allow blood from the IVC to drain into the right atrium, might be used as a shunt. A second tape tourniquet placed around the suprarenal IVC is applied.
- After control of the inflow to the retrohepatic IVC is achieved, the retroperitoneal vessels are accessed by inferomedial retraction of the liver, and the venous injury is repaired with interrupted or running 3-0 or 4-0 nonabsorbable monofilament suture.

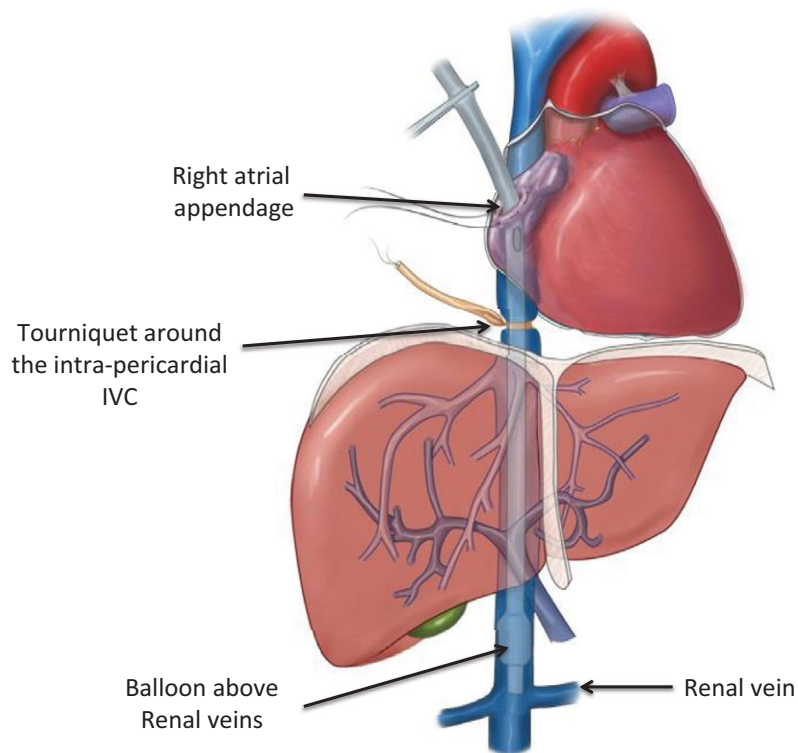


Figure 33.20 Illustration of atriocaval shunt in place. A size-8 endotracheal tube, with a side-hole cut at about 8–10 cm from the clamped proximal end of the tube, is inserted through the purse-string in the right atrial appendage. The tube is guided into the IVC, the balloon is inflated just above the renal veins, and the tape tourniquet around the intrapericardial IVC is tightened.

(a)

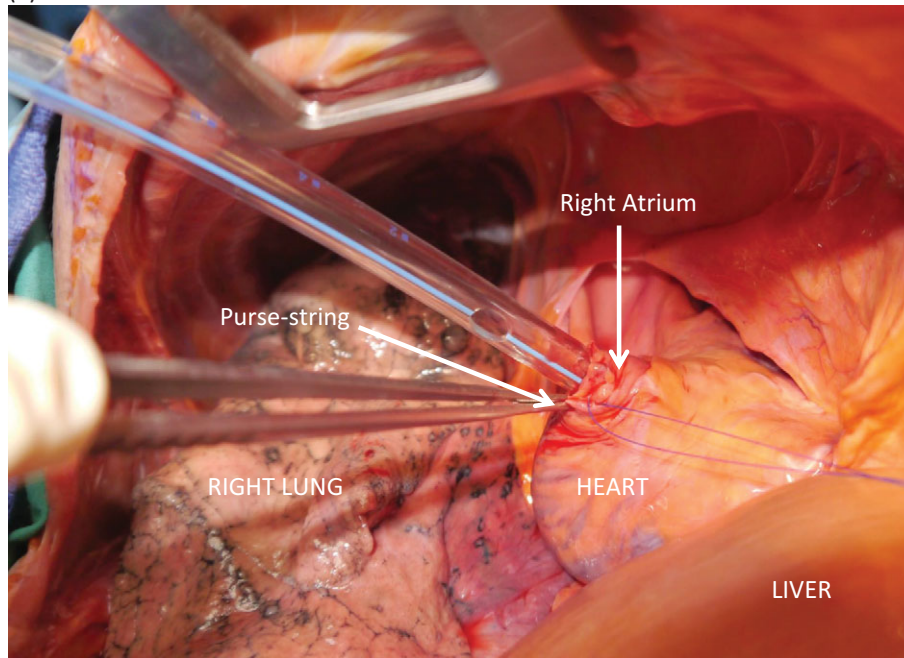
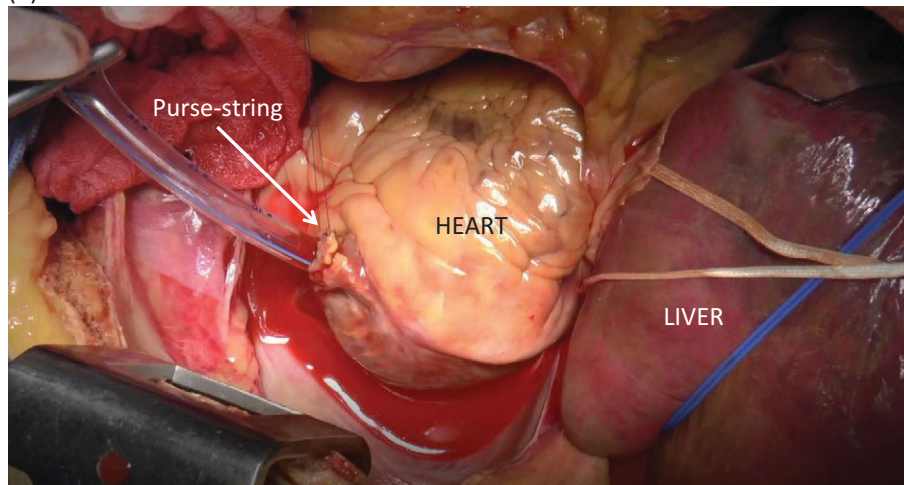


Figure 33.21 (a) Atriocaval shunt. A purse-string suture is placed in the right atrial appendage and a small hole is made in the appendage. The shunt is inserted into the atrium carefully and advanced into the IVC. **(b)** The shunt is inserted through the purse-string and advanced into the IVC until the tip of the tube is felt slightly distal to the renal veins.

(b)



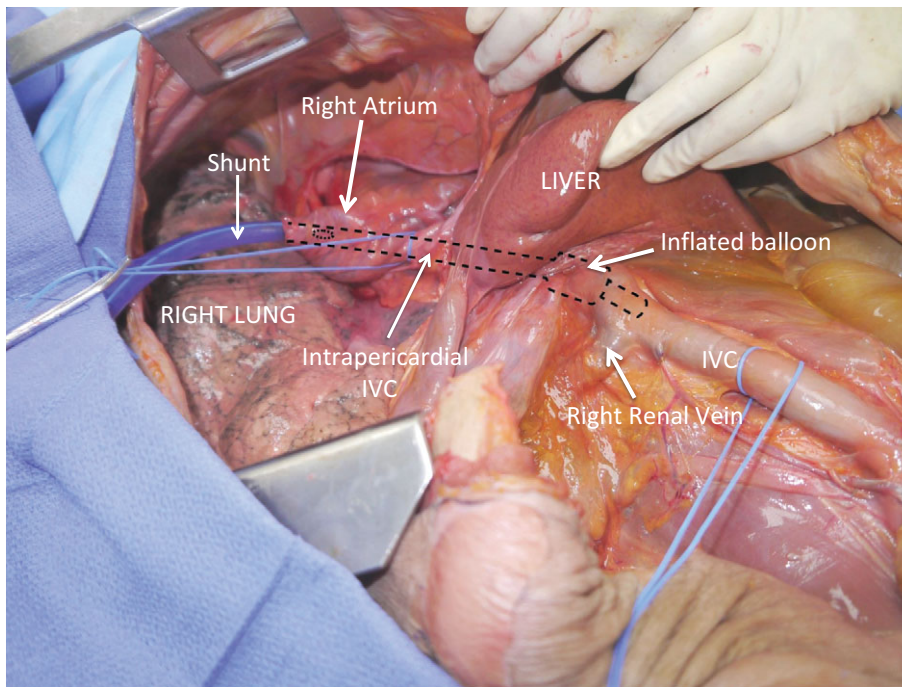


Figure 33.22 Atriocaval shunt (endotracheal tube) in place. The balloon of the tube is inflated slightly above the renal veins.

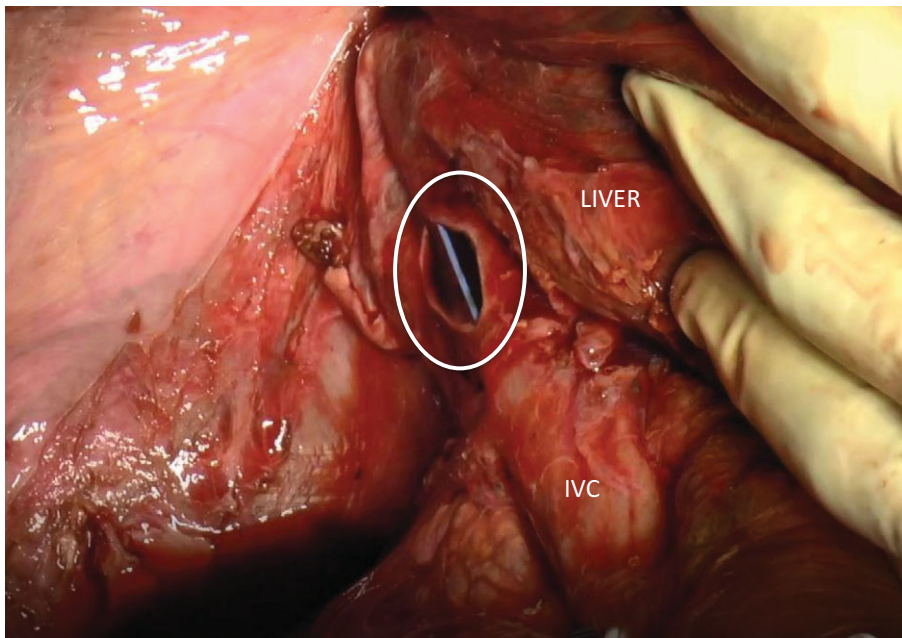


Figure 33.23 Atriocaval shunt in place. The right lobe of the liver is rotated medially and the injury to the retrohepatic IVC is exposed (circle).

Tips and Pitfalls

- In suspected abdominal vascular injuries, the femoral veins should not be used for line placement in case the victim has an injury to the IVC or the iliac veins
- Resist the temptation to expose a contained retrohepatic IVC injury! A disaster is likely to occur!
- In damage control for suspected retrohepatic vein injuries, do not place packs behind the liver! The liver should be compressed posteriorly against the IVC.
- During mobilization of the infrarenal IVC, proceed carefully to avoid injury to the lumbar veins. The avulsed vein retracts and is difficult to find.
- During exploration of a caval injury, there is high risk for air embolism. Prevent this complication by early direct compression, followed by proximal and distal control.
- Following IVC ligation the lower extremities and feet should be wrapped with elastic bandages to reduce edema. Monitor closely for extremity compartment syndrome.
- Following damage control packing or repair of IVC injuries, the patient should not be over-resuscitated.
- In the appropriate cases, consider placement of the atriocaval shunt early, before the patient is “in extremis.”
- During placement of the atriocaval shunt, manually guide the tube into the IVC. It often curls into the heart!

Cesarean Section

Marcia Ciccone, Sigita Cahoon, and Laila I. Muderspach

Surgical Anatomy

- The overall pelvic anatomy and orientation of the pelvic organs is similar to the nongravid state (see [Chapter 35](#) Emergency Hysterectomy) with the following exceptions:
 - Prior to the 12th week of pregnancy, the uterus is protected by the bony pelvis, but as it grows out of the pelvis, it becomes more susceptible to injury. By 20 weeks, the fundus reaches the umbilicus, and gestational age may be estimated by fundal height. The number of centimeters above the pubic symphysis corresponds to the estimated gestational age in weeks.
 - Physiologic changes in blood flow that result in diffuse engorgement of the uterine, ovarian, and salpingeal vasculature. Gravid or postpartum hysterectomies are more difficult and result in higher blood loss than when performed in the nongravid setting. Damage to this vasculature can quickly lead to exanguination.

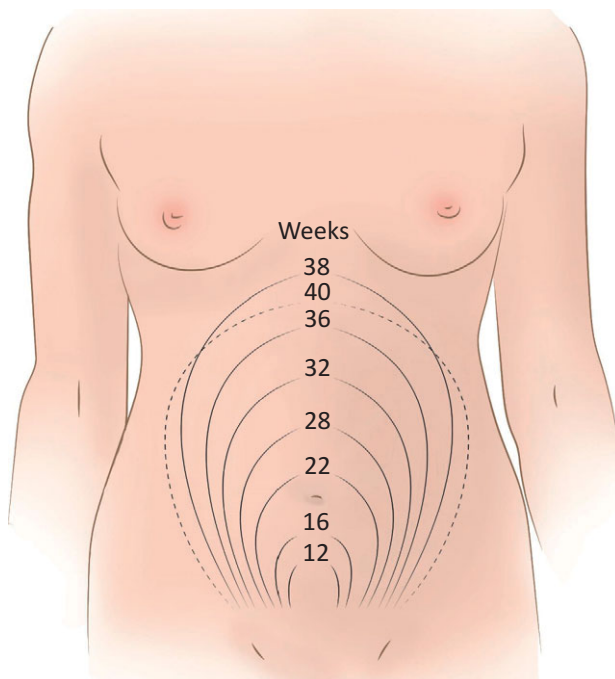


Figure 34.1 Estimate of gestational age based on fundal height: pubis symphysis 12 weeks, umbilicus 20 weeks.

Physiologic Changes in Pregnancy

- Cardiac output increases by 30–50% due to increased stroke volume and heart rate.
- After 20 weeks, the pressure of the gravid uterus on the inferior vena cava (IVC) may limit cardiac output. At term, the IVC becomes completely occluded in the supine position.
- Unless contraindicated, in advanced pregnancy the patient should be positioned in left lateral decubitus to reduce pressure on the IVC and improve venous return to the heart. A wedge may also be placed under the right hip.
- Blood pressure decreases due to decreased systemic vascular resistance.
- Maternal oxygen reserve is decreased, rendering pregnant patients more susceptible to hypoxia, hypercapnia, and respiratory acidosis.
- Blood volume increases and the maternal blood pressure may be maintained despite significant blood loss.
- Be aware of both increased risk of VTE and DIC in pregnancy.

General Principles

- Trauma is the leading cause of nonobstetrical maternal death. Blunt trauma is commonly associated with placental abruption, while penetrating trauma is more likely to cause direct fetal injury.
- On arrival, in advanced pregnancy, position the patient supine with a left lateral tilt. Supplemental oxygen should be given at 10L via face mask to increase fetal oxygenation and to keep oxygen saturations above 95%.
- Aggressively replete fluids and replace volume prior to using vasopressors, as these may reduce uterine blood flow.
- Assessment of gestational age (GA) is paramount to decision-making. This can be estimated via:
 - Most reliable method: calculation from patient-provided estimated due date (EDD), if available, especially if this date was confirmed by a first trimester ultrasound (ask the patient).
 - Calculation from reported LMP may be helpful to get a general sense of GA, but is often imprecise.

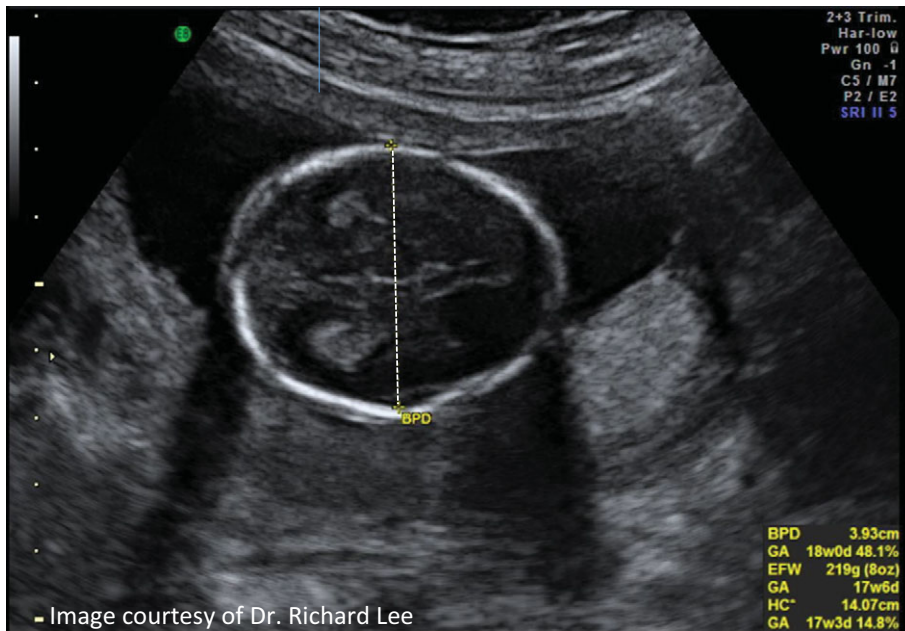


Figure 34.2 Appropriate biparietal diameter measurement from outer to inner table of the skull.

- Ultrasonography: Perform a quick measurement of the biparietal diameter (BPD), measured from the outer table of the bony calvarium on one side to the inner calvarium on the opposite side. The image should be taken at an axial plane at the level of the thalami and cavum septum pellucidum and is easiest to find in a third trimester patient by placing the probe just above the pubic symphysis in a transverse orientation.
- If no ultrasound is available, a measurement of fundal height may suffice to corroborate the dating the patient has given. As a rule of thumb, if the fundus is 2–4 fingerbreadths above the umbilicus, the pregnancy is likely over 20 weeks and likely to be viable.
- Maternal and fetal well-being are both at stake and must be considered.
 - In the setting of cardiopulmonary arrest, a perimortem emergent cesarean section may be performed (see section on perimortem cesarean below).
 - Maternal benefit is prioritized since fetal survival, particularly prior to viability (22–23 weeks, depending on the capabilities of proximal neonatal ICU facilities), is inextricably linked to maternal well-being.
 - If previable, fetal heart tones should be assessed via Doppler or ultrasound; if viable, a fetal heart rate monitor should be used (normal FHR 110–160 bpm). Ensure fetal and maternal heart rates are not confused.
 - In general, emergency cesarean delivery is indicated:
 - For fetal benefit due to impending maternal death or fetal heart rate tracing abnormalities, and only after the age of viability
 - For maternal benefit in the setting of cardiopulmonary arrest, not responsive to

resuscitative efforts, to decompress the IVC if the uterine fundus is above the umbilicus

- Rh/ Kleihauer-Betke (KB) test and alloimmunization prevention:
 - Fetomaternal bleeding occurs frequently, and can result in fetal anemia and/or maternal alloimmunization.
 - Unless maternal blood is known to be Rh+, rho gam should be given 300 mcg IM in any incidence of trauma to prevent alloimmunization.
 - The KB test can be sent to measure the percent of fetal hemoglobin in maternal blood and is used to estimate if additional rho gam is needed.

Special Surgical Instruments and Sutures

- Ten blade scalpel
- Monopolar electrocautery device
- Curved Mayo and Metzenbaum scissors
- Bandage scissors
- Russian forceps
- Retractors:
 - Balfour (aka bladder blade) retractor
 - Richardson retractor
 - Goulet retractors
- Suture: 0-vicryl or 0-chromic suture for hysterotomy closure
- Clamps:
 - Ring forceps
 - Kocher clamps
 - Pean clamp for umbilical cord

Preoperative Preparation

The patient is positioned in the left lateral decubitus position with a wedge or support under the right hip. The operating room table may also be tilted. Within 1 hour before skin incision, Cefazolin 1 g IV is given (2 g is given if the patient weighs more than 80 kg). Clindamycin 900 mg with Gentamycin 5 mg/kg is an alternative for penicillin allergy. The pubic hair is clipped over the mons pubis, and a Foley catheter

is placed. If general anesthesia is used, delivery should be expeditious to minimize fetal exposure to anesthetics.

Incision

- A vertical midline incision extending from the symphysis pubis to the subumbilical region should be made to facilitate exposure and evaluation the remainder of the abdomen/pelvis. It can be extended as needed to evaluate the remainder of the abdomen. The fascia and muscles should be opened to the pubic symphysis to maximize exposure.
- If the indication for surgery is not trauma, the surgeon may consider low-transverse incision, if he or she is familiar with this incision. For some obstetricians, a Pfannenstiel incision provides easier and more rapid abdominal entry.

Procedure

- After entering the peritoneal cavity, identify the uterus and pelvic structures and note the degree of uterine rotation.
- Ensure that the incision (skin, peritoneum, fascia, and muscle) is adequate for rapid delivery of the infant before proceeding with hysterotomy.
- Deciding on uterine incision:
 - Low transverse: used when the lower uterine segment is developed (wide enough to permit delivery of the fetal head). With this incision, if only one or two cesareans have been performed, women may undergo trial of labor (TOLAC) in subsequent pregnancies. This is the preferred incision for routine term cesareans.
 - Transfundal/classical: an incision through the uterine fundus. This incision mandates subsequent cesarean deliveries due to risk of uterine rupture with labor. It is used in the setting of severe prematurity, if the lower uterine segment is not developed, placenta previa, and accreta (to avoid a low-lying anterior placenta), or a fetus in transverse lie back down position. This incision is preferred in an unstable patient to avoid cervical or vascular laceration.
 - Low vertical: a vertical incision through the midline; permits future TOLAC, but data is limited.

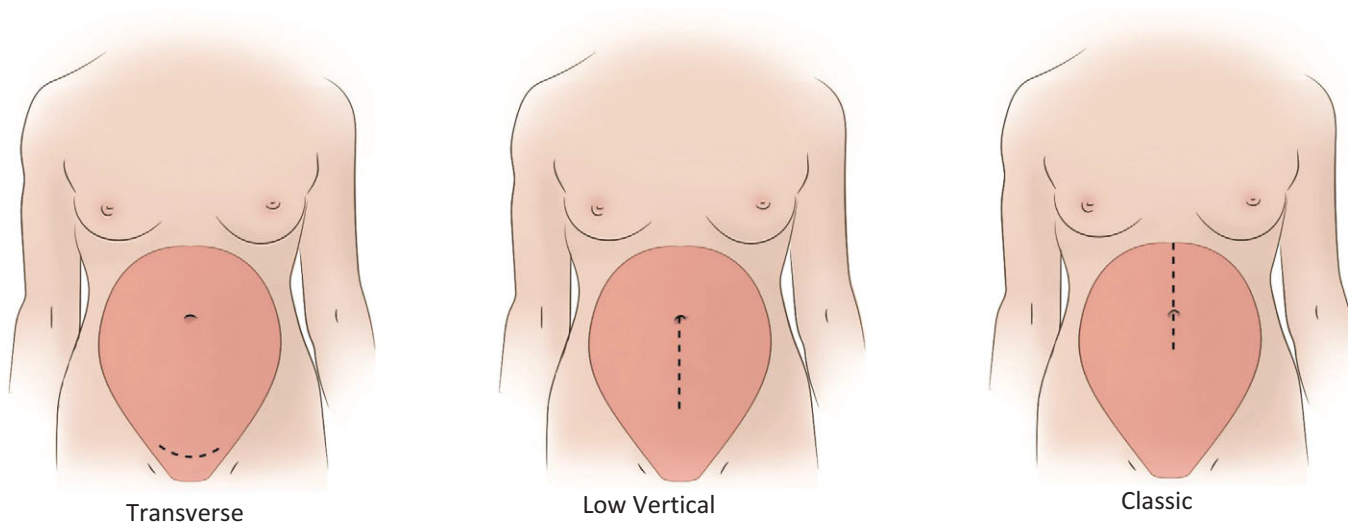


Figure 34.3 Types of uterine incisions.

- Create the bladder flap (optional, depending on time, but protective against bladder injury) by picking up the midline lower uterine segment serosa just where it becomes loose on the uterus, and sharply nick the serosa with Metzenbaum scissors. Next, undermine the serosa laterally from the initial incision using the Metzenbaum scissors and divide it. Remove and replace the bladder blade to deflect the bladder inferiorly.
- Hysterotomy: Incise the uterus with the scalpel taking serial strokes in a 1–2 inch plane and clearing the blood away with a Yankauer suction tip between strokes until the fetal membranes are encountered.

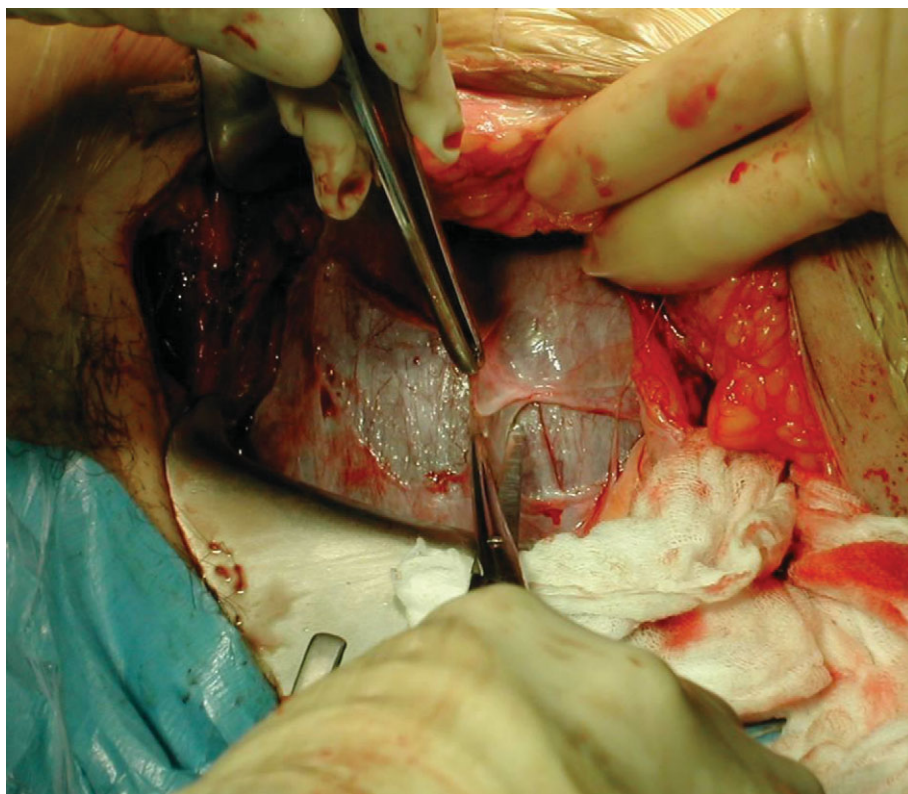


Figure 34.4 Creation of the bladder flap and reflection of the bladder inferiorly.

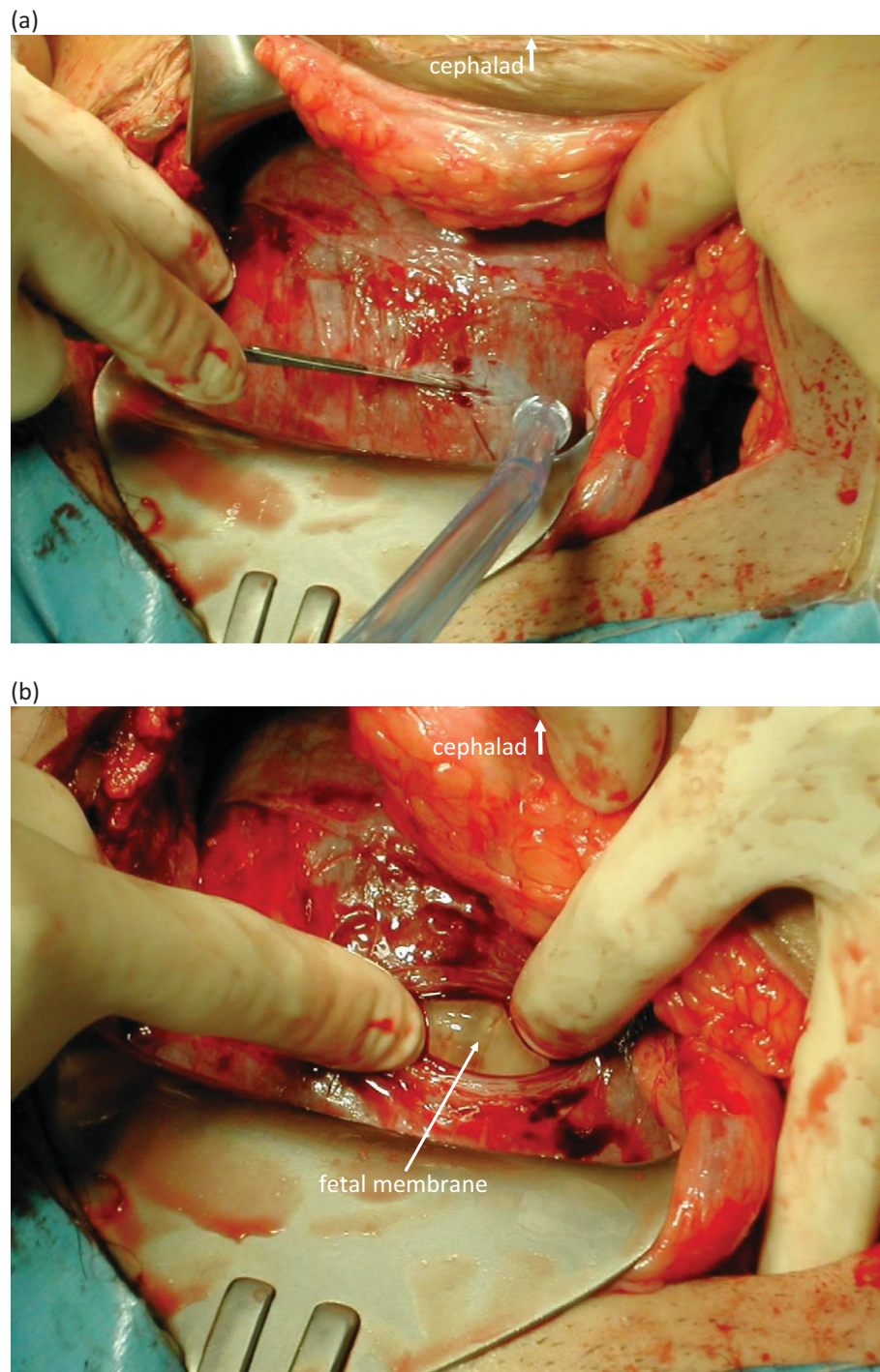


Figure 34.5 (a) Low transverse uterine incision. (b) Incise the myometrium until the membranes are reached. (c) Stretch the uterine incision laterally and superiorly to obtain space for delivery prior to rupturing the membranes.

(c)

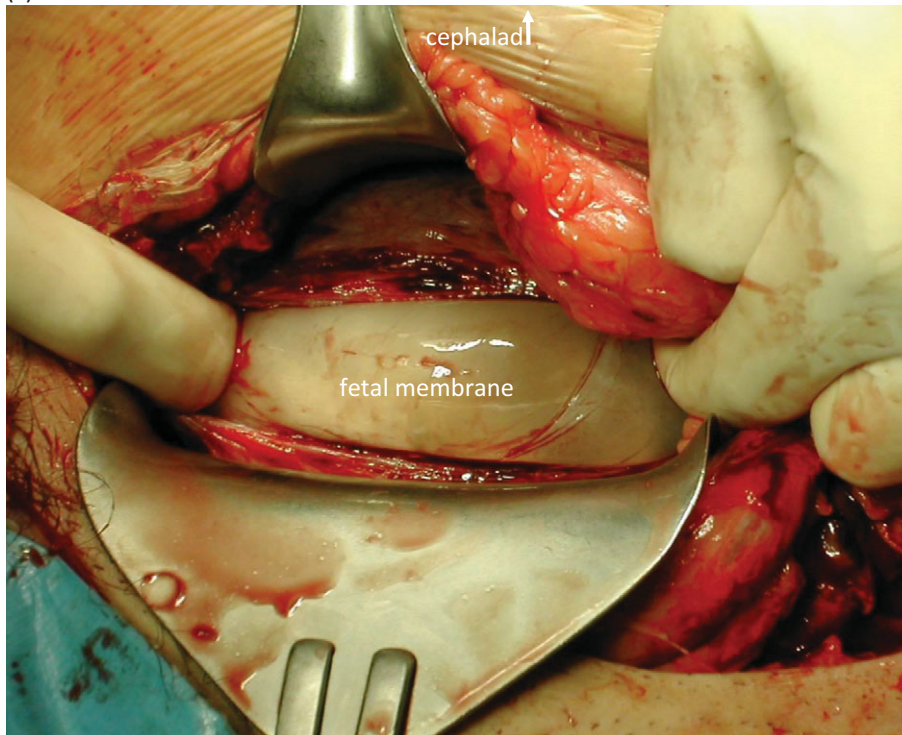
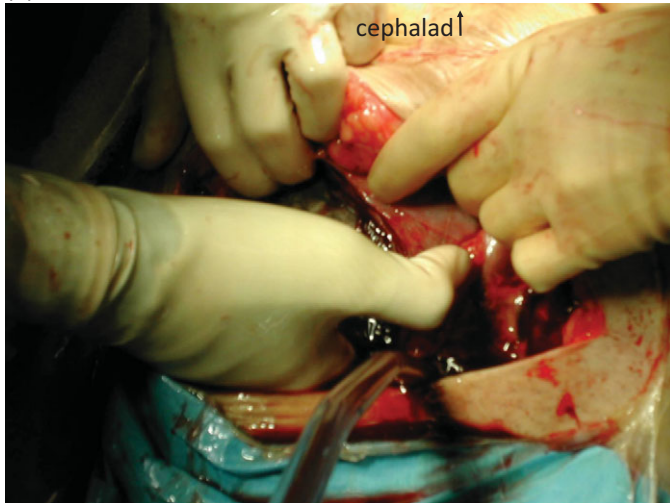


Figure 34.5 (cont.)

- Ideally, the fetal membranes are not ruptured with the scalpel in order to prevent iatrogenic fetal injury and allow time for widening the uterine incision if necessary, but this does frequently happen on entry and is ok.
- If the fetal membranes are intact, they will bulge out of the hysterotomy. If needed, the hysterotomy should be extended using bandage scissors. If a vertical or fundal incision, this would be extended directly inferior or superior. Inferiorly, one must take care not to damage the bladder, which is peritonealized against the lower uterine segment.
- If a low transverse uterine incision has been made, the incision can be stretched laterally by gently pulling apart the superior and inferior aspects of the incision. If bandage scissors are used, the corners of the incision should be extended vertically to avoid the lateral uterine vasculature (Figure 34.5c).
- The membranes are then ruptured by grasping the bulging membrane at the center of the incision with an Allis clamp and pulling gently.
- The steps of delivery depend on the fetal position:
 - Vertex
 - Insert hand into hysterotomy and under the fetal head.
 - Elevate the fetal head out of the pelvis to the level of the incision by lifting the delivering hand cephalad. Excessive movement of the wrist may result in extension of the hysterotomy into the cervix or bladder, so the surgeon delivering the infant may need a stool or the table should be lowered so that he or she has adequate leverage to elevate the head.
 - If a nuchal cord is present, an attempt should be made to reduce it around the fetal head by gently displacing it around the head. If it is too tight to reduce, the infant can be delivered with the cord in place around the neck.

(a)



(b)

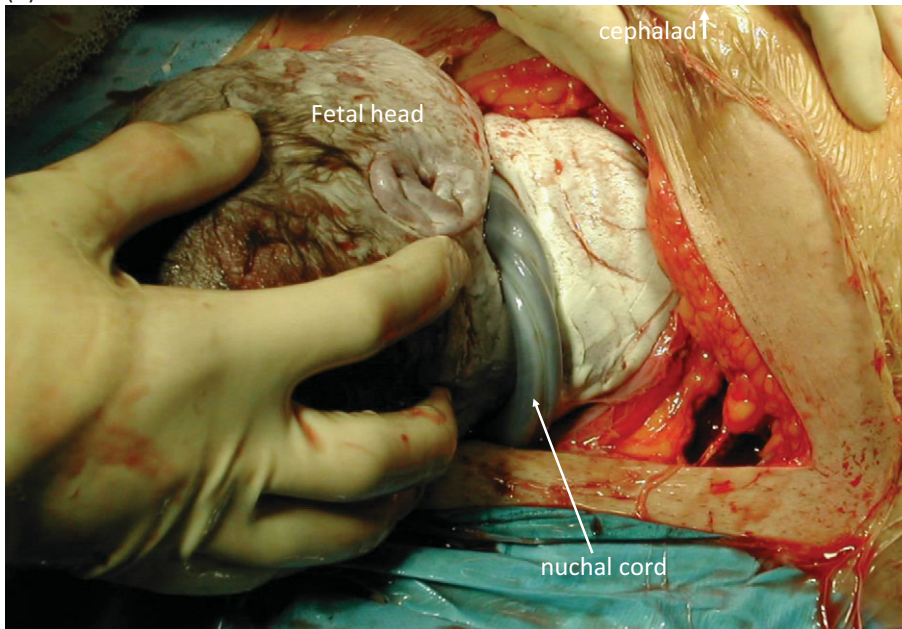


Figure 34.6 (a) Insert the hand into hysterotomy and under the fetal head and elevate it out of the pelvis. (b) Elevate the head out of the uterus and if present, reduce the nuchal cord or deliver through it.

- Once head is at incision, maintain the surgeon's hand supporting the head, and an assistant applies fundal pressure, while the surgeon guides the fetal head and body out of the hysterotomy.

- Breech

- Insert surgeon's hand and elevate the presenting part (may be buttocks or bilateral lower extremities) to the hysterotomy.
- Once the presenting part is at the hysterotomy, an assistant should apply fundal pressure to deliver the presenting part.
- Once the hips have delivered, a moist towel should be placed over the buttocks, the infant rotated, and the upper extremities, one at a time, swept through the incision.
- Flex the fetal head by elevating the body and gently depressing the infant's chin by placing a

finger in the mouth or by placing a hand on the infant's maxilla to complete delivery of the fetal head. This prevents hyperextension and injury to the infant's neck.

- If a transverse incision has been made and the surgeon is unable to deliver the fetus using the above steps, the incision can be extended vertically in an upside-down T incision. If the incision is vertical, it should be extended toward the fundus. This will also require that the patient cesarean sections for future pregnancies.

- Cord clamping

- Doubly clamp and divide the cord using two Pean clamps at least 4 inches (or more) from the infant's umbilicus.
- Deliver the placenta via manual extraction or fundal massage with gentle traction on the umbilical cord.

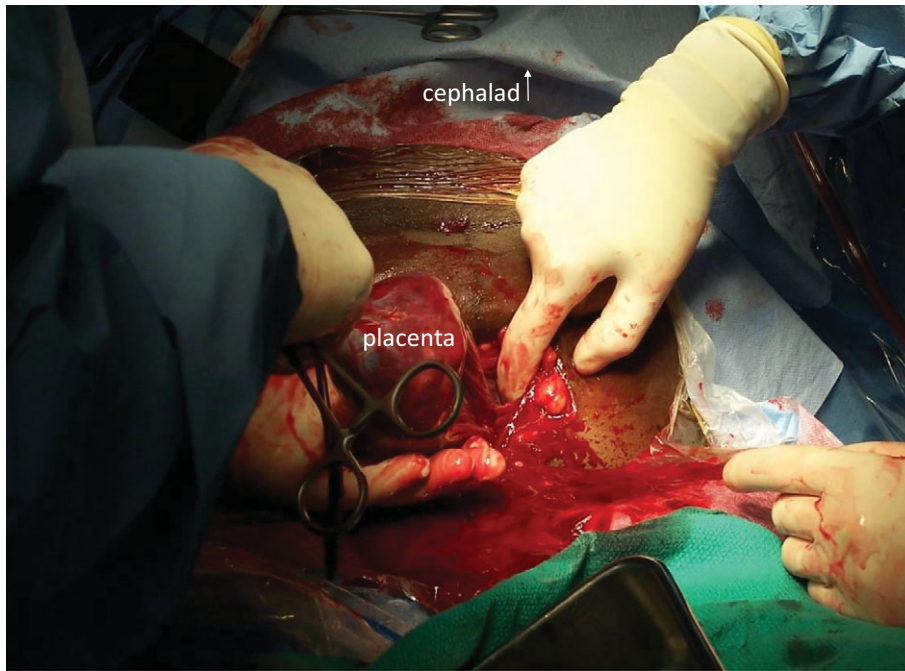


Figure 34.7 Delivery of the placenta.

- Once the placenta is almost completely removed a ring forceps should be used to extract remaining fetal membranes.
- Exteriorize the uterus by inserting a hand behind the fundus and pulling the fundus out of the incision.
 - Clean out the endometrial cavity with a dry lap sponge to ensure all fetal membranes have been removed. Retained membranes or placental fragments can cause postpartum hemorrhage and/or infection.
- Hysterotomy closure
 - Clamp the angles of the incision and areas of rapid bleeding using ring forceps.
 - Close the hysterotomy in two layers using an 0-Vicryl or 1-Chronic suture.

- For the initial layer, perform a running-locked stitch, taking care to avoid the uterine vessels laterally for a transverse incision.
- A second imbricating layer of the same suture should then be added to complete closure.

After closure, apply pressure to bleeding areas as an initial measure. If superficial or on a peritoneal or serosal edge, an attempt may be made to cauterize this with Bovie. If deeper or coming around suture lines and pressure does not result in hemostasis, figure-of-eight or interrupted sutures may be placed for hemostasis.



Figure 34.8 Exteriorize the uterus and clean the endometrium with a dry lap sponge.

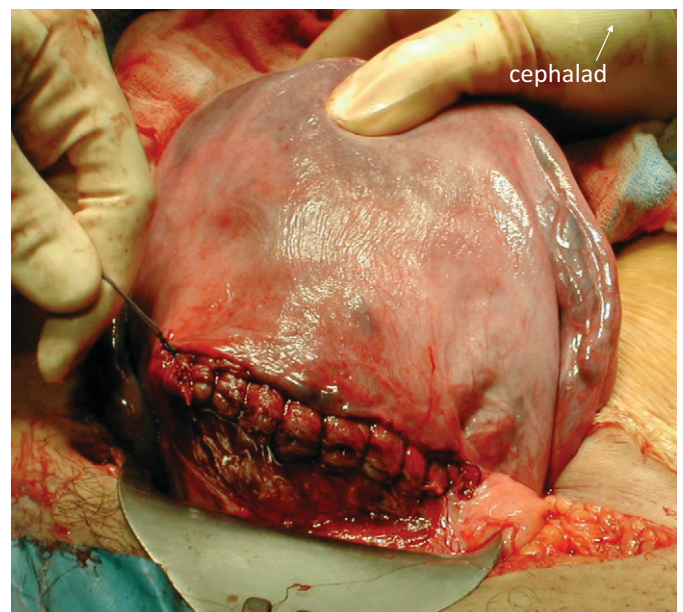


Figure 34.9 Closure of the hysterotomy. The first layer of running locked suture is completed. An imbricating layer follows.

- Replace the uterus into the abdomen following hysterotomy closure and assurance of hemostasis.
- Remove blood clots and clean out amniotic fluid that may have collected in the pelvis using lap sponges.
- Reexamine the hysterotomy for hemostasis and address any further bleeding using the above mechanisms.

Perimortem Cesarean Section

- Maternal cardiac arrest affects 1 in 12,500 deliveries in the US.
- Resuscitative measures
 - CPR should be performed supine on a hard surface. In nonpregnant patients, CPR produced 30% of normal cardiac output at best. However, in pregnant patients, cardiac output from CPR can be closer to 10%.
 - Left lateral positioning may decrease quality of cardiac compressions.
 - ACLS
 - Defibrillation and all medications should be used as for a nonpregnant patient.
 - Epinephrine is preferred to vasopressin.
 - Do not withhold medications for concerns about teratogenicity.
- Aortocaval compression from the third trimester uterus significantly reduces cardiac output.
 - Relieving compression increases for venous return and may increase efficacy of chest compressions.
 - Maternal neurologic damage occurs after more than 5 minutes of anoxia.
 - Measures to decrease aortocaval compression:
 - Position the patient with a left lateral tilt.
 - Transabdominally, displace the uterine fundus to the left by manually pushing on the uterine fundus.
 - Delivery of the fetus via perimortem cesarean/resuscitative hysterotomy can result in 60–80% increase in cardiac output. Maternal hemodynamics, chance of ROSC, and overall resuscitative management may greatly improve.
- Timing of delivery
 - Four-minute rule: delivery should be initiated within four minutes of the onset of cardiopulmonary arrest, if it has not yet been successful. Delivery should be achieved within five minutes of unsuccessful attempts at resuscitation.
 - Results in more successful maternal resuscitation, potentially preventing maternal neurologic damage.
 - The sooner the infant is delivered after maternal cardiac arrest, the greater likelihood of intact neonatal survival.
 - Maternal survival ranges from 15 to 60%, and fetal survival ranges from 60 to 80%.
- Procedure:
 - Perform the C-section in the emergency room. No time should be wasted to transfer the patient to the operating room. Splash the abdomen with betadine or omit abdominal preparation and give IV antibiotics postoperatively.
 - Perform an extended midline vertical skin incision with a low vertical or low transverse hysterotomy.
 - Remove the placenta and close the hysterotomy and abdomen expeditiously.
 - Continue CPR throughout.

(a)

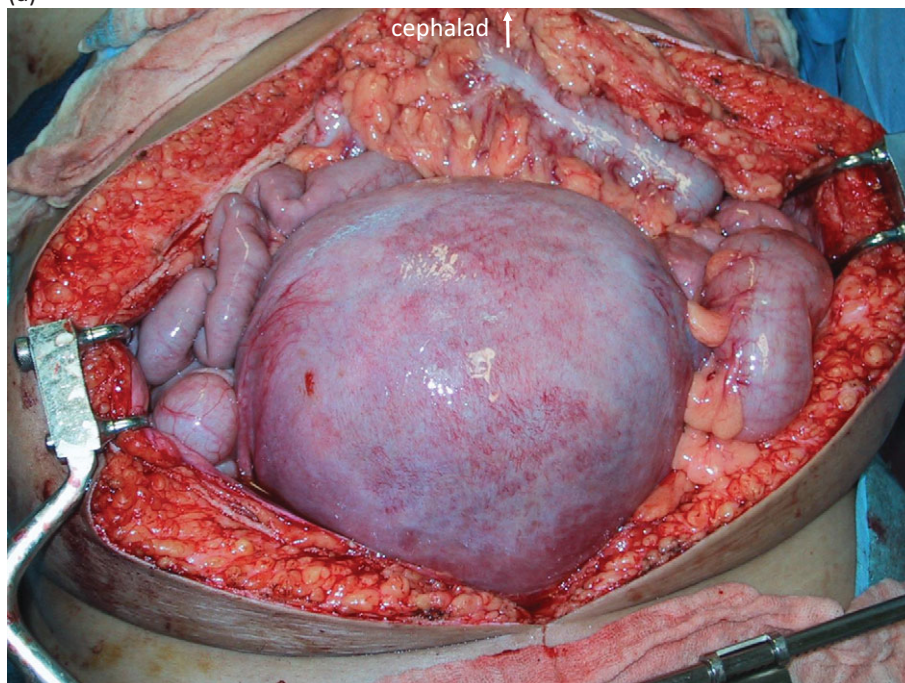


Figure 34.10 (a) Perimortem Cesarean Section. The incision should be extended to allow quick and adequate exposure of the uterus and identification of any intra-abdominal injury. Emergency Room Perimortem Cesarean Section. Hemostatic closure of the hysterotomy (circle) (b) after delivery of the fetus (c) and the placenta (d).

(b)



(c)



(d)

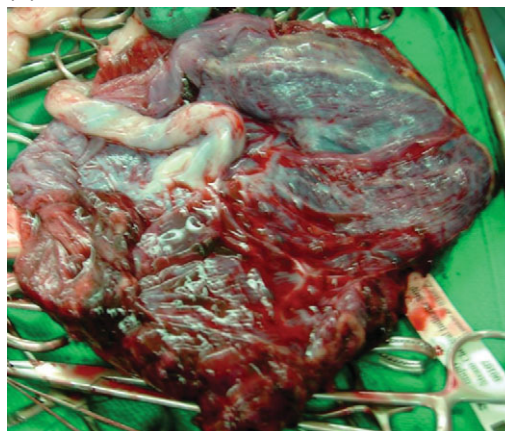


Figure 34.10 (cont.)

Tips and Pitfalls

- For urgent cesarean delivery (if delivery is needed within several minutes), the fascia is nicked in the midline and extended bluntly using bilateral traction. Similarly, the peritoneum can be entered bluntly, and stretched to visualize the uterus.
- Remember to counsel patients that they will require cesarean sections for future pregnancies due to high risk of uterine rupture with TOLAC if a classical or T-shaped uterine incision has been performed or if you are performing their second (or more) low-transverse cesarean.

Emergency Hysterectomy

Marcia Ciccone, Laila I. Muderspach, and Sigita Cahoon

Surgical Anatomy

- The uterus, adnexa, superior bladder, and upper rectum are peritonealized. These structures attach to the pelvis and to one another via a variety of peritoneal reflections and vascular and fibrous ligaments and pedicles.
 - Pelvic organs:
 - Reproductive organs: uterus, fallopian tubes, ovaries
 - Rectum: separated from the uterus by the posterior cul-de-sac, or Pouch of Douglas
 - Urinary system:
 - Bladder: shares a common peritoneal lining with the lower uterine segment and cervix
 - Ureters: Common sites for injury during gynecologic procedures:
 - Near the pelvic brim when the ovarian vessels are divided for oophorectomy
 - Along the peritoneum during retroperitoneal pelvic dissection
 - At the cardinal ligament during transection of the uterine arteries, where the ureter crosses under the uterine vasculature (“water under the bridge”)
 - At the lateral angles of the vaginal cuff closure

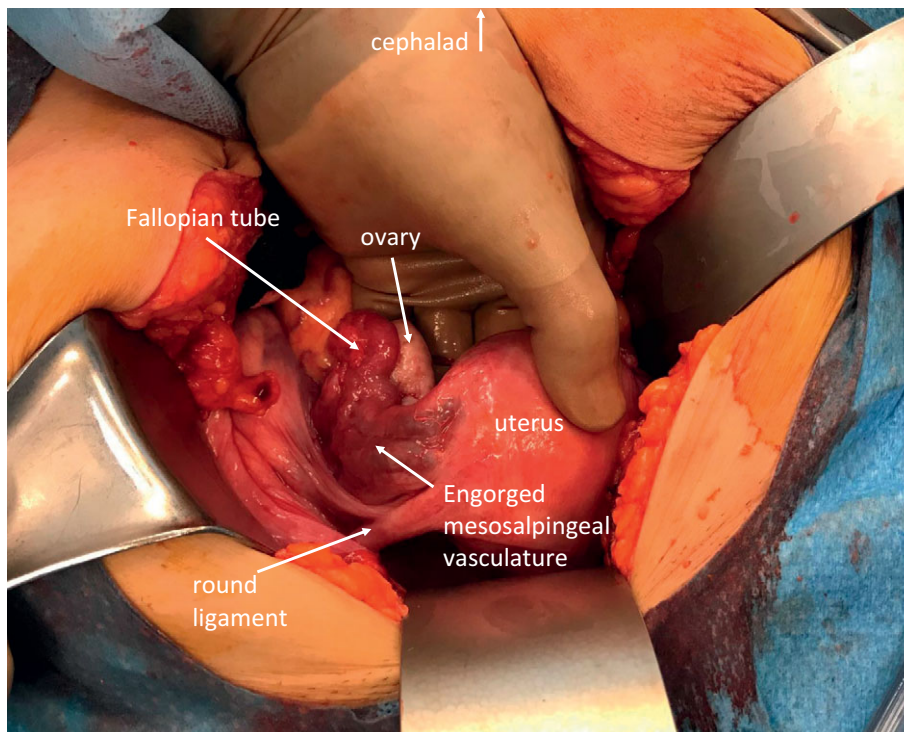


Figure 35.1 Surgical photo showing uterus, tube, ovary, and round ligament.

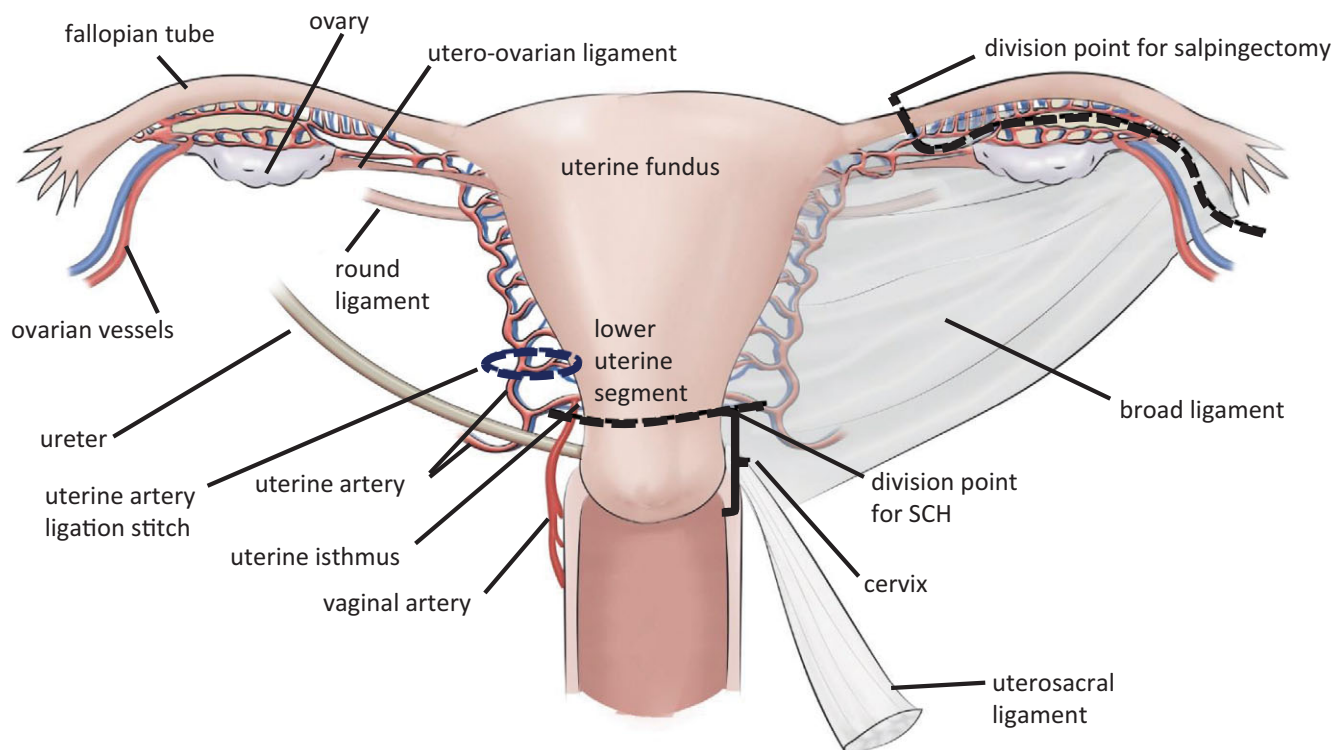


Figure 35.2 Anatomy of the female genitourinary tract depicted from a posterior view. Dotted lines indicate where to divide when performing a supracervical hysterectomy and a salpingectomy. An additional dotted oval demonstrates where a uterine artery ligation stitch can be placed to control bleeding. The ureter is shown crossing from posterior to anterior under the uterine vessels which course from lateral to medial.

• Vascular pedicles:

- Ovarian vessels: branch from the aorta (right ovarian vein drains to IVC and left ovarian vein to the left renal vein) and supply the adnexa
- Uterine vessels: branch medially from internal iliac vessels and course toward then along the uterus
- Parametrial/vaginal vessels: branches of the internal iliac arteries that course through the parametria

• Ligaments and peritoneal reflections:

- Utero-ovarian ligament: connects ovaries to uterus
- Mesosalpinx: peritoneal reflection that suspends the fallopian tube and contains mesosalpingeal vessels
- Round ligament: extends from the bilateral uterine cornua and courses through the deep inguinal ring
- Broad ligament: peritoneal reflection attaching the uterus to the round ligament, adnexa, and sidewall
- Cardinal ligament: the connection between the lower uterine segment/cervix and pelvic sidewall
- Uterosacral ligament: connects the base of the cervix to the sacrum

General Principles

- If the uterus has been injured, repair is usually more expeditious and less morbid than hysterectomy. Take into consideration feasibility based on location and extent of damage, as well as the patient's age and reproductive wishes.
 - If the defect involves the lateral uterus, the uterine vasculature may be compromised. Attempt to clip or suture ligate bleeding in this area. If the bleeding cannot be controlled, hysterectomy is indicated.
 - In reproductive-age women, if the ovaries or tubes have been damaged and are bleeding, an attempt should be made to coagulate bleeding from these structures using cautery. If not possible, use suture ligation or surgical clips. However, if the damage to the adnexal structures is extensive, they should be excised. Use of a LigaSure cautery device, if available, may facilitate removal of adnexal structures.
 - The fallopian tube can be divided from the ovary and the mesosalpinx cauterized with the LigaSure device or the vasculature can be suture-ligated. The

fallopian tube can be divided at least 1–2 cm or more distal from the uterine cornua, using the LigaSure or a suture-ligation technique (see Figure 35.2).

- Defects in the uterine body, fundus, or lower uterine segment should be repaired with either 0-vicryl or chromic suture in a figure-of-eight or running locked fashion.
 - Even very large defects may be repaired if the uterine blood supply is not significantly compromised.
 - Document repair technique, location, size, orientation, and thickness of the defect. If full-thickness, the patient may need cesareans for future pregnancies, and she should be notified postoperatively.
 - Repair should ideally be a two-layer closure in a reproductive-age woman. A single layer is sufficient if hemostasis is achieved in patient who has completed childbearing or if the time for a second layer would compromise the patient.
 - If the defect is very small and is not bleeding, it may not require repair.
 - Ensure the bladder is not involved if the defect is in the cervix or lower uterine segment.
- If the above primary repair techniques do not work, uterine artery ligation or embolization may help control bleeding.
 - Uterine artery ligation: Using a 0-vicryl stitch at the uterine isthmus, place a figure-of-eight suture in a horizontal plane encircling the uterine arteries, which can be identified by palpation. Anchoring each stitch solidly into the underlying myometrium medial to the uterine arteries, come out through the broad ligament superior and lateral to the uterine vessels. Tie the suture tightly lateral to the vessels.
 - Consider hypogastric or uterine artery embolization (UAE).
 - Be aware that ligation or embolization may result in postoperative pain and low-grade fever. Fertility outcomes after permanent embolization are not well-studied.

Special Surgical Instruments and Sutures

- Bookwalter retractor
- LigaSure electrothermal device is desirable

Preoperative Preparation

Hysterectomy may be performed in either the supine or dorsal lithotomy position. Both arms may be abducted. Give preoperative Cefazolin 2 g IV (3 g may be given if the patient weighs >120 kg) with re-dosing every 4 hours or after each 1,500 mL of surgical blood loss. In a penicillin allergic patient, alternatives may include IV Clindamycin 900 mg or Metronidazole 500 mg with Gentamicin 5 mg/kg, Aztreonam 2 g or Ciprofloxacin 400 mg is an alternative.

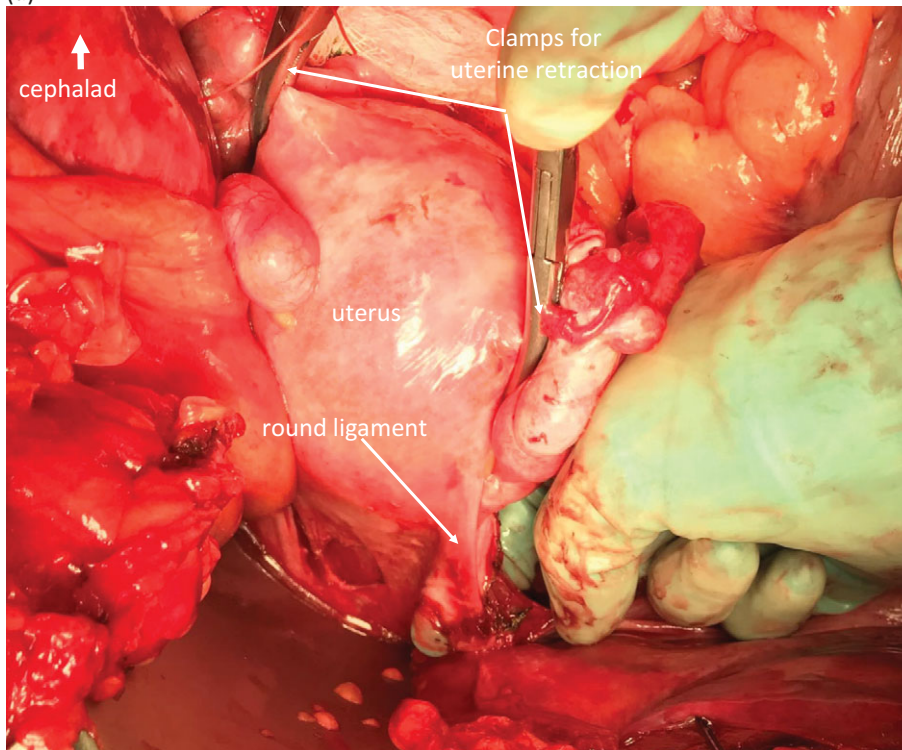
Incision

- To facilitate pelvic exposure, make a vertical midline incision and open the fascia to the pubic symphysis, separating the rectus and pyramidalis muscles to this level as well. Extend the peritoneal incision as inferiorly as possible.

Procedure

- The uterus and pelvic structures should be identified. Pean clamps may be placed on the cornua or triple pedicle (medial fallopian tube, utero-ovarian ligament, and round ligament) to facilitate uterine retraction.
- Divide the round ligament bilaterally:
 - Incise the peritoneum superior and inferior to the round ligament and create a window in the peritoneum parallel to the round ligament. Place a pean clamp on the lateral aspect of the ligament.
 - Divide the round ligament using Bovie or LigaSure cautery and suture-ligate the divided lateral end.
 - The medial pedicle often does not always need to be suture-ligated, but may be, if heavily vascular.

(a)



(b)

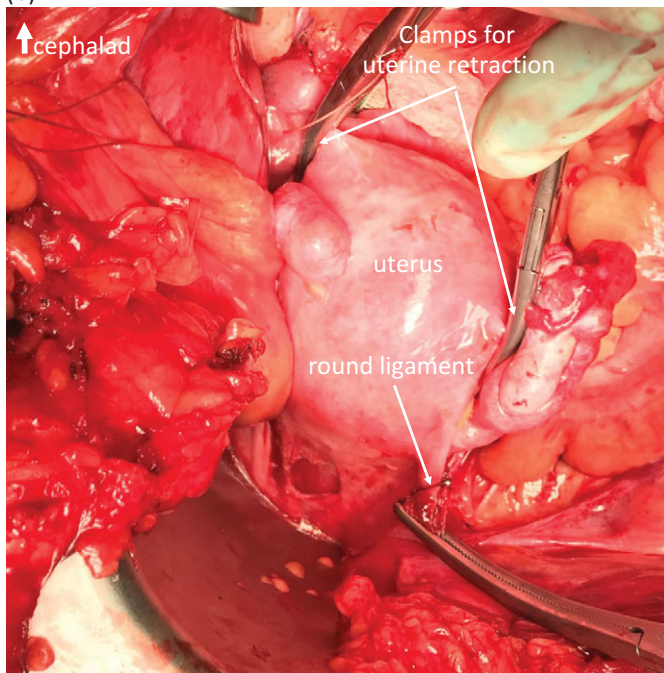


Figure 35.3 (a) Isolate the round ligament by dividing the anterior and posterior peritoneum. Pean clamps are placed over the cornua and triple pedicle bilaterally to retract the uterus. (b) The round ligament is clamped with a pean laterally and a surgical clip medially prior to division. This step may also be completed by simply cauterizing slowly through the round ligament or by using the LigaSure system, depending on how vascular it appears.

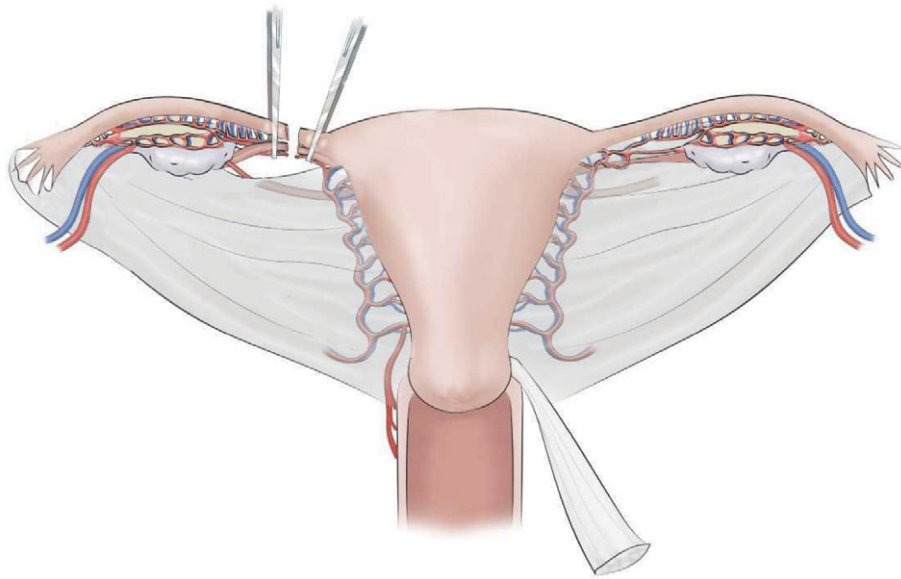


Figure 35.4 Depiction of division of the fallopian tube and utero-ovarian ligament for an adnexal-sparing procedure. The left side of the diagram shows proper clamp placement over the fallopian tube and utero-ovarian ligament, with a window in the peritoneum below.

- Decide to keep or remove ovaries:
 - If the ovaries are damaged, bleeding, abnormal appearing, or inseparable from the uterus, one or both may be removed. Consider the patient's age, menopausal status, and fertility desires.
- Ovarian-sparing procedure:
 - Locate an avascular window in the broad ligament, inferior to the utero-ovarian ligament and fallopian tube, and divide the peritoneum to create an opening parallel to the utero-ovarian ligament. Ensure that this is large enough to place two clamps with sufficient distance apart to divide the pedicle approximately 1–2 cm.
 - Clamp the pedicle with two slightly curved Haney or Zeppelin clamps, with the curve of the clamps facing one another. Cut the pedicle between the two clamps with curved Mayos. Place a free tie of 0-vicryl first on the ovarian pedicle and open and close (flash) the clamp while the first knot is pushed down. Then suture ligate around the same clamp with 0-vicryl. Free tie the uterine pedicle, and remove the clamp.
- Salpingo-oophorectomy procedure:
 - Tenting up the peritoneum using DeBakey forceps, extend the peritoneal incision from the posterior aspect of the round ligament parallel and lateral to the fallopian tube, ovary, and ovarian vessels, staying approximately 1–2 cm lateral to these structures and undermining the peritoneum such that just the peritoneal layer is divided. Continue this incision cephalad until the sigmoid or cecum is reached.
 - Locate the ureter either transperitoneally or intraperitoneally by either palpation or direct visualization. It is usually deep/posterior to the ovarian vessels.
 - Find an avascular space in the peritoneum between the ureter and the ovarian vessels and incise this with the Bovie, and extend this peritoneal incision along the vessels until two Haney or Zeppelin clamps can be placed on the ovarian vessels with sufficient distance to divide the pedicle.

(a)

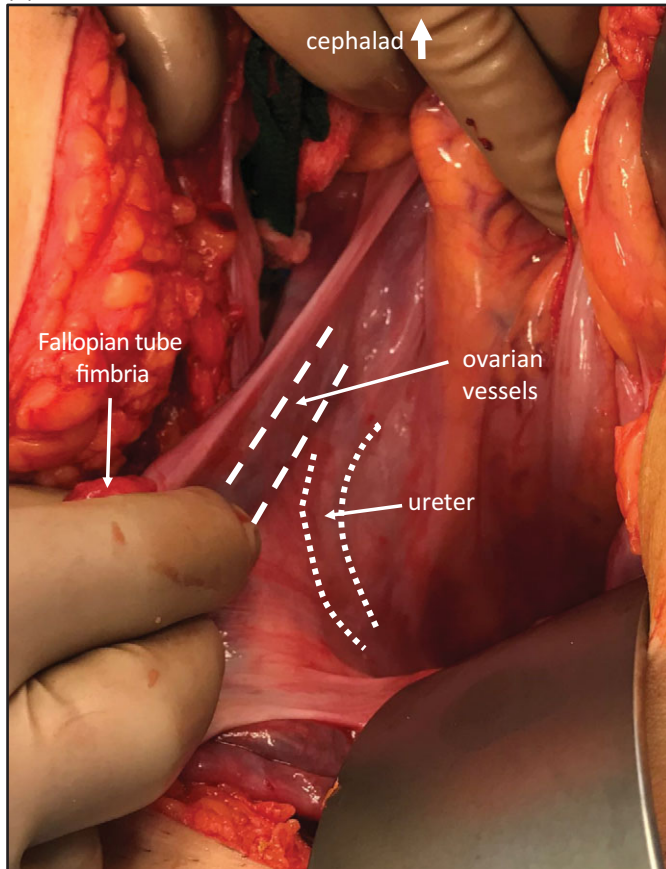
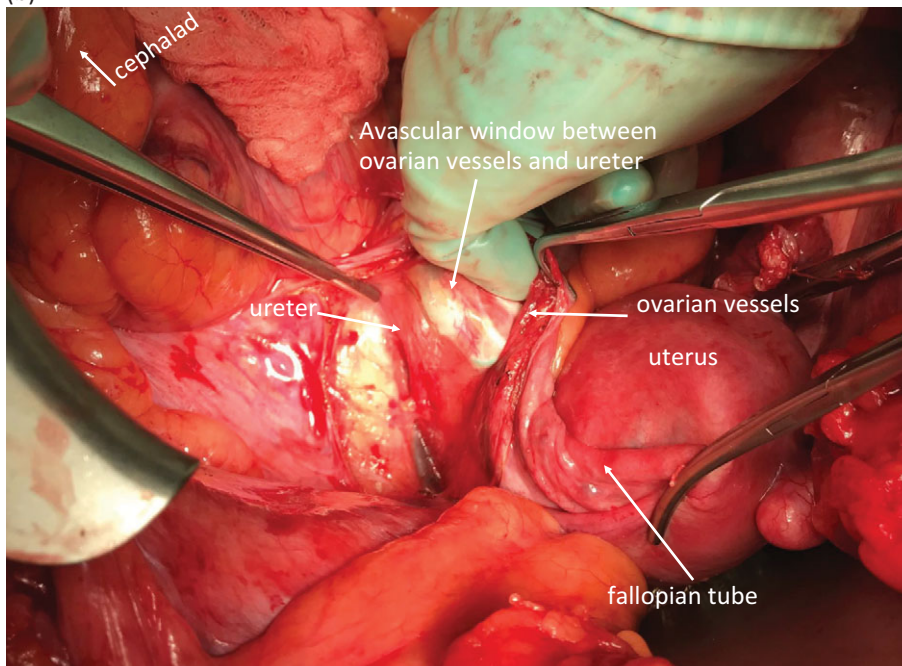


Figure 35.5 (a) Identification of the ureters. The ovary and fallopian tube are held laterally in the surgeon's hands and the ureter is identified by visualizing peristalsis through the peritoneal surface. The ureter feels like a rubber band when palpated on the medial leaf of the broad ligament. **(b)** The ureter is identified after the retroperitoneum has been opened. The ovary and tube are pulled medially and the ureter is located deep to the ovarian vessels on the medial leaf of the divided peritoneum (broad ligament). **(c)** Doubly clamp and divide the ovarian vessels proximal to the tube and ovary.

(b)



(c)

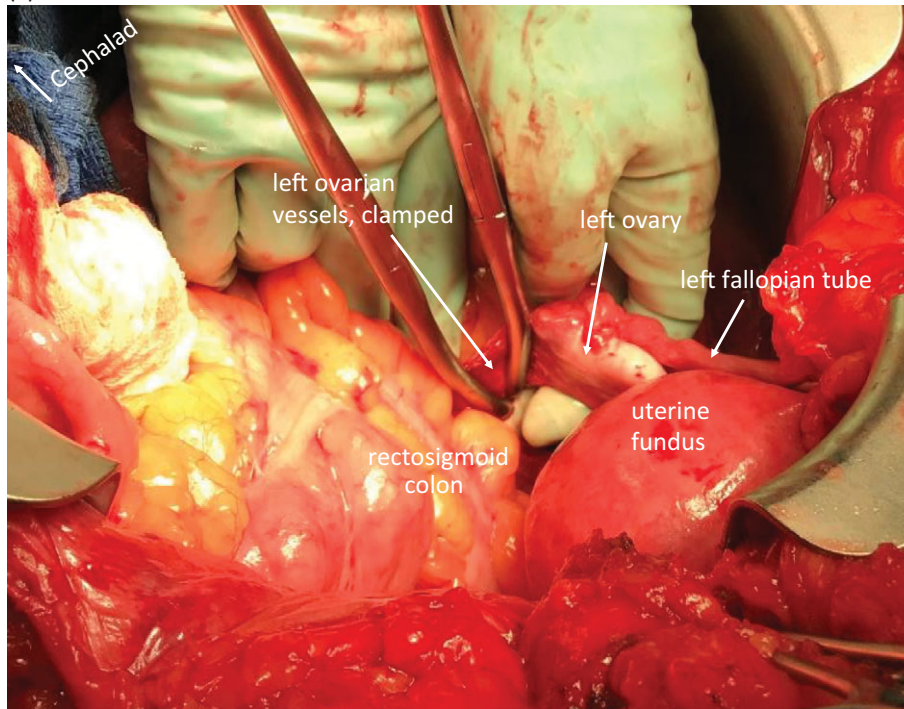


Figure 35.5 (cont.)

- Place two clamps with tips facing one another and approximately 1–2 cm apart. Place each clamp at the lateral-most part of the pedicle, and divide the vessels between the two clamps (Figure 35.5c).
- Place a free-tie of 0-vicryl behind the vascular pedicle, and open and close (flash) the clamp, while the first knot is pushed down. A second suture should be used to suture-ligate or free-tie the same pedicle with 0-vicryl. Ligate the ovarian side with a free-tie of 0-vicryl.
- Using Bovie cautery, divide the broad ligament parallel to and inferior to the adnexa toward the uterus.
- Decide on supracervical (SCH) vs. total abdominal hysterectomy (TAH)
 - SCH is faster and easier than total hysterectomy, requires less expertise, less bladder dissection, and results in lower blood loss. There is also less risk of damage to the bladder and ureters.
 - SCH is preferred in an emergent situation unless there is damage to the cervix that cannot be fixed with SCH or in the presence of a known pathology, such as uterine or cervical cancer.
- Creation of the bladder flap and mobilization of the bladder:
 - Creation of the bladder flap brings the ureters inferiorly away from the uterine arteries to prepare for ligation and permits safe division of the cervix from the vagina and closure of the vaginal cuff. If a supracervical hysterectomy is planned, the bladder does not need to be dissected off of the entire cervix but just far enough so that the cervix can be safely amputated and closed.
 - From the round ligament, the broad ligament peritoneum continues to cover the lower uterine segment, cervix, and bladder in a single sheet, bringing the posterior bladder to rest peritonealized against the cervix and lower uterine segment. In women with prior cesareans, this anatomy may be altered and the plane between the bladder and cervix/lower uterine segment may be adherent and difficult to separate.
 - The peritoneum spanning the round ligament to the junction of the bladder and uterine peritoneum is incised, using cautery. A thin layer of peritoneum is tented up, using DeBakey forceps. The peritoneum is undermined to separate it from the underlying tissue prior to dividing it. It is first divided inferiorly, then the incision aimed medially toward a point 1–2 cm anterior to the uterus where the peritoneum becomes loose and can be easily picked up with forceps.

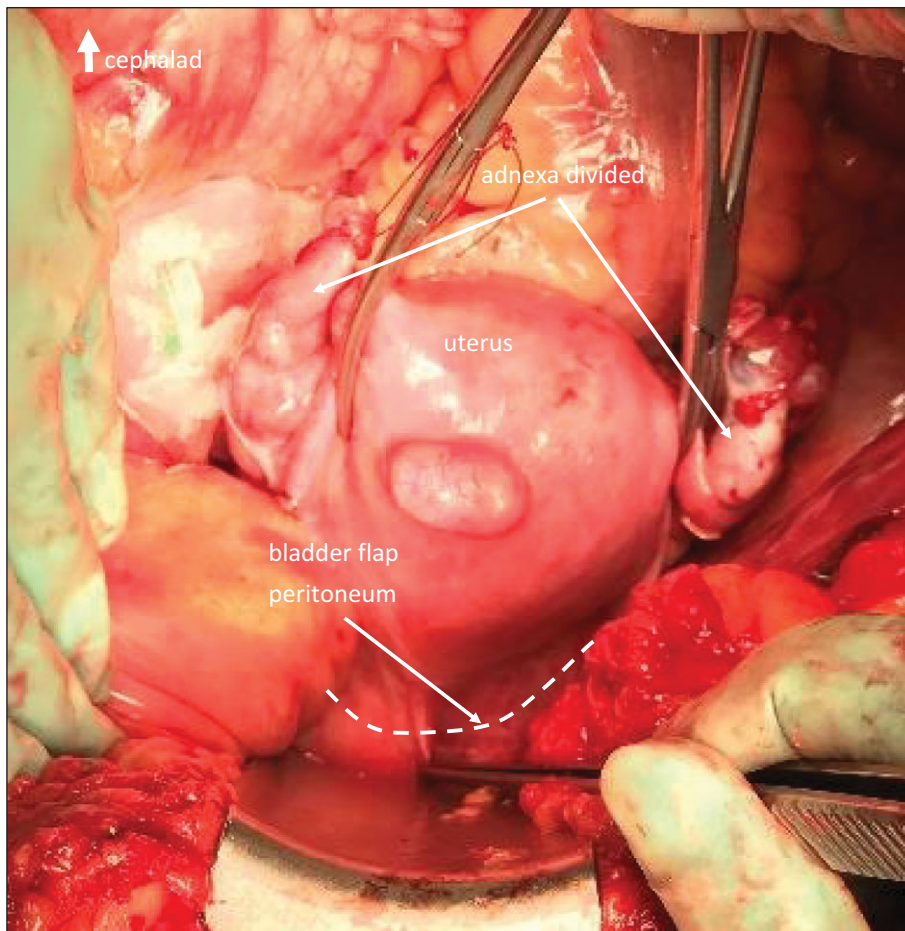


Figure 35.6 Creation of the bladder flap between the LUS and bladder. The dotted line outlines where the peritoneal incision should be made from one round ligament to the contralateral one. The peritoneum is elevated off of the underlying tissue and undermined, as it is divided to avoid damage to the bladder and underlying vessels.

- This is repeated from the opposite side until the incisions meet at the above noted point.
- Using a Debakey forceps, the bladder peritoneal edge is retracted anteriorly and superiorly, while the uterus is pulled superiorly and posteriorly. Good traction enhances visualization of the loose areolar tissue, indicating the avascular plane between the uterus/cervix and bladder. This space should be dissected with a combination of cautery and gentle blunt dissection

until the bladder has been pushed away and down approximately 2 cm past the end of the cervix (for a total hysterectomy), or 2–3 cm past the point where the cervix will be divided (for a supracervical hysterectomy). Identification of the white endopelvic fascia covering the cervix and vagina indicates that the correct plane has been dissected.

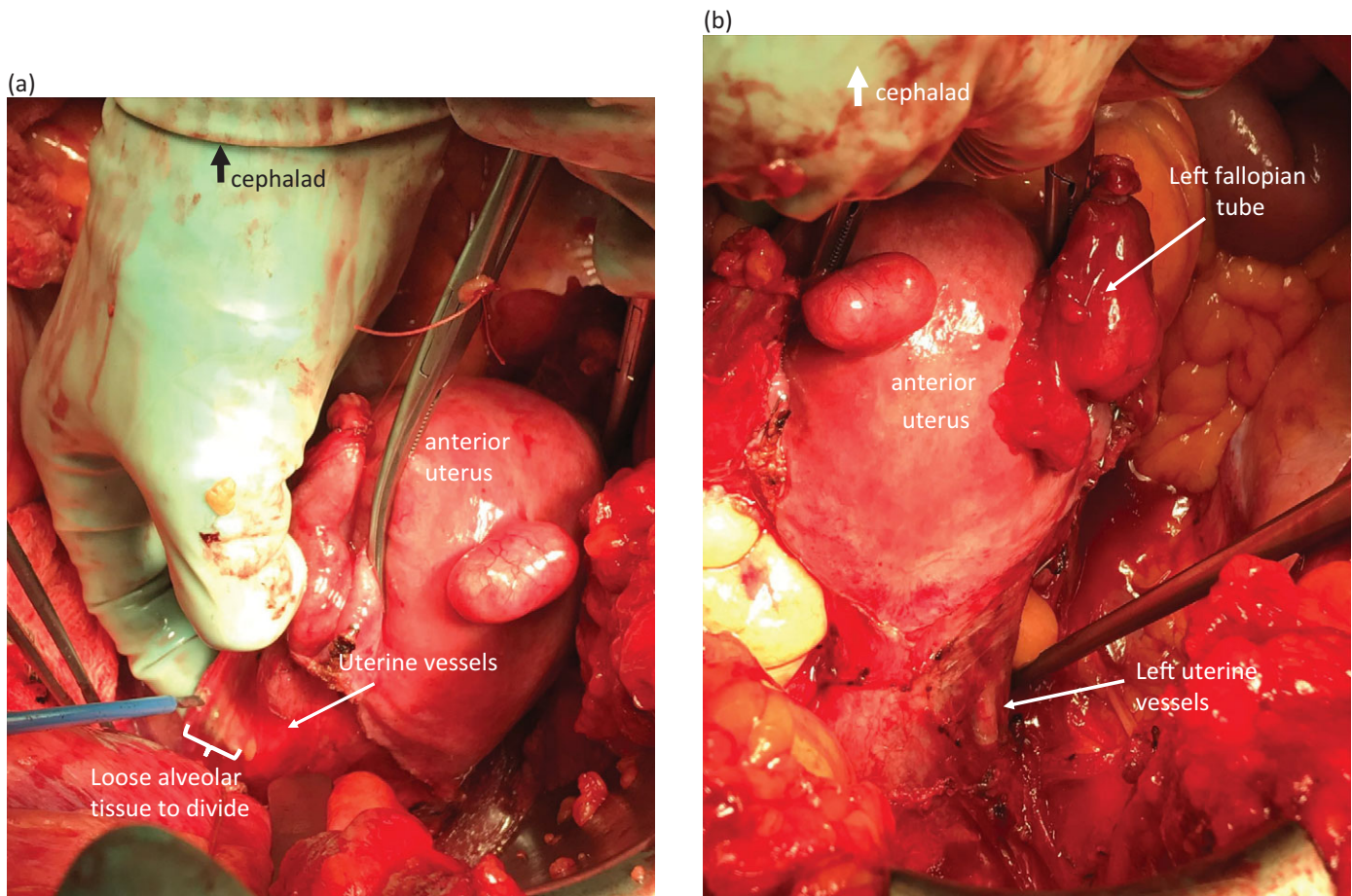


Figure 35.7 (a) Isolation of the uterine arteries. Retract loose alveolar tissue and posterior peritoneal leaves laterally and divide to expose the uterine vessels. This is shown on the patient's right. (b) Uterine arteries skeletonized and ready for division on the patient's left side.

- Skeletonize uterine arteries:
 - This drops the ureters inferiorly and away from the uterine arteries, making suture ligation safer.
 - Using a Debakey forceps, gently pull segments of avascular tissue lateral to the uterine arteries away, and divide them using Bovie cautery with lateral

downward traction. The remaining avascular tissue and posterior peritoneum adjacent to the uterus should be divided such that the uterine vessels are exposed as they course superiorly along the lateral uterus, at the level of the uterine isthmus (where the uterus meets the cervix or at the level of the internal cervical os).

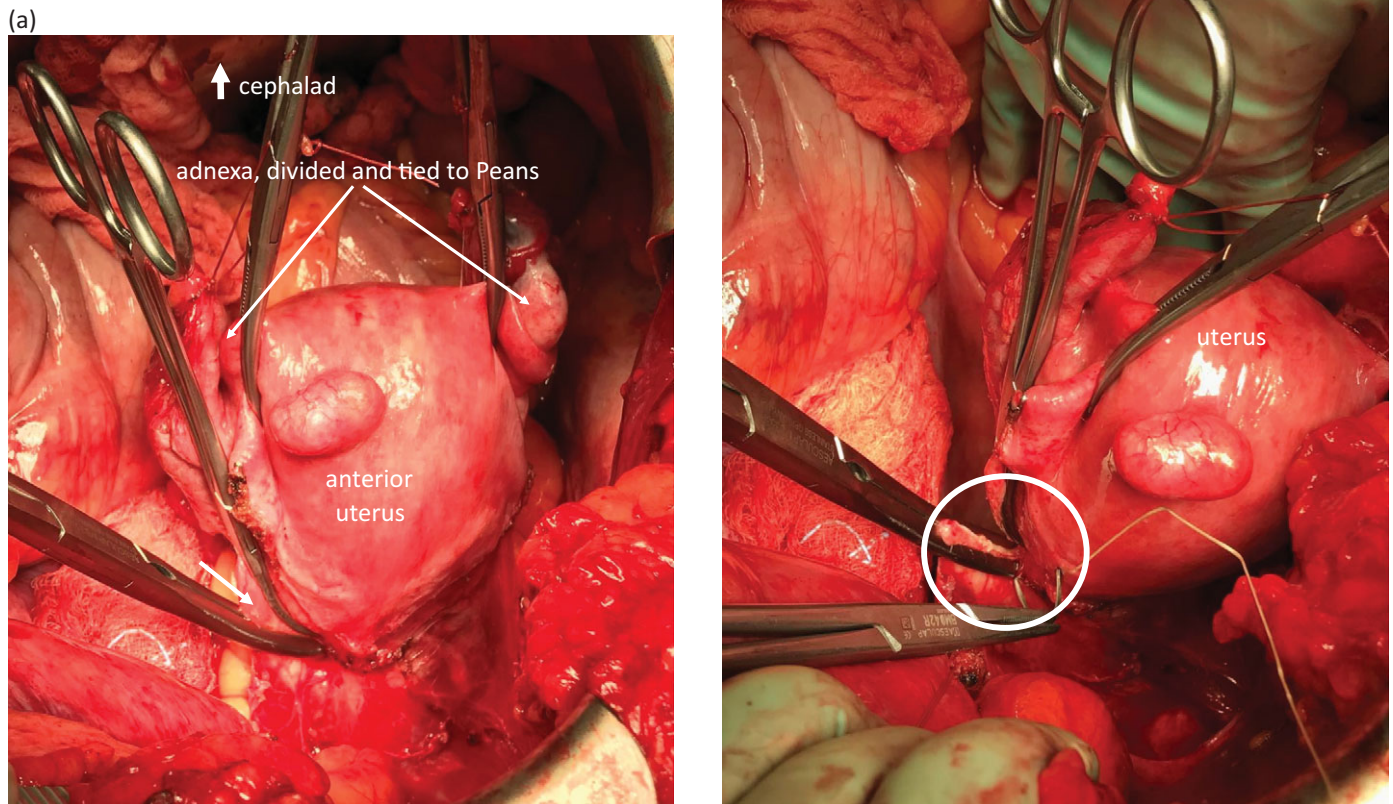


Figure 35.8 (a) Division of the uterine arteries. A curved Zeppelin clamp is placed across the vessels (black arrow) perpendicularly, at the uterine isthmus. A hemostat is used to control back-bleeding. The tips of both clamps meet medially at the cervix. (b) Suture-ligation (circle) of the uterine arteries after division with scissors. The suture is inserted just under the inferior tip of the clamp and tied down behind the clamp.

- Divide the uterine arteries at the uterine isthmus:
 - Placing the initial clamp lower on the cervix risks damaging the ureter.
 - Place a slightly curved Haney or Zeppelin clamp over the uterine arteries at the level of the uterine isthmus. Direct the clamp such that the straight portion of the clamp is perpendicular to the vessels and the end of the clamp directly abuts the superior cervix. A second, smaller clamp, such as a hemostat or pean, is placed tip-to-tip with the initial clamp, but angled up against the uterus to control back-bleeding from the uterine side of the vessels.
- The vessels are divided between the clamps using curved mayo scissors and cutting the tissue to just within the tip of the clamps.
- A 0-vicryl suture is placed at the inferior-medial tip of the larger/distal clamp first. The suture must be placed so that the needle brushes against the corner of the clamp as it is passed through. The needle is removed and the suture tied down behind the clamp. Once the first knot is secure and on tension, the clamp is removed, and the remaining knots are thrown. The uterine pedicle can be tied off in a similar fashion and the hemostat removed.

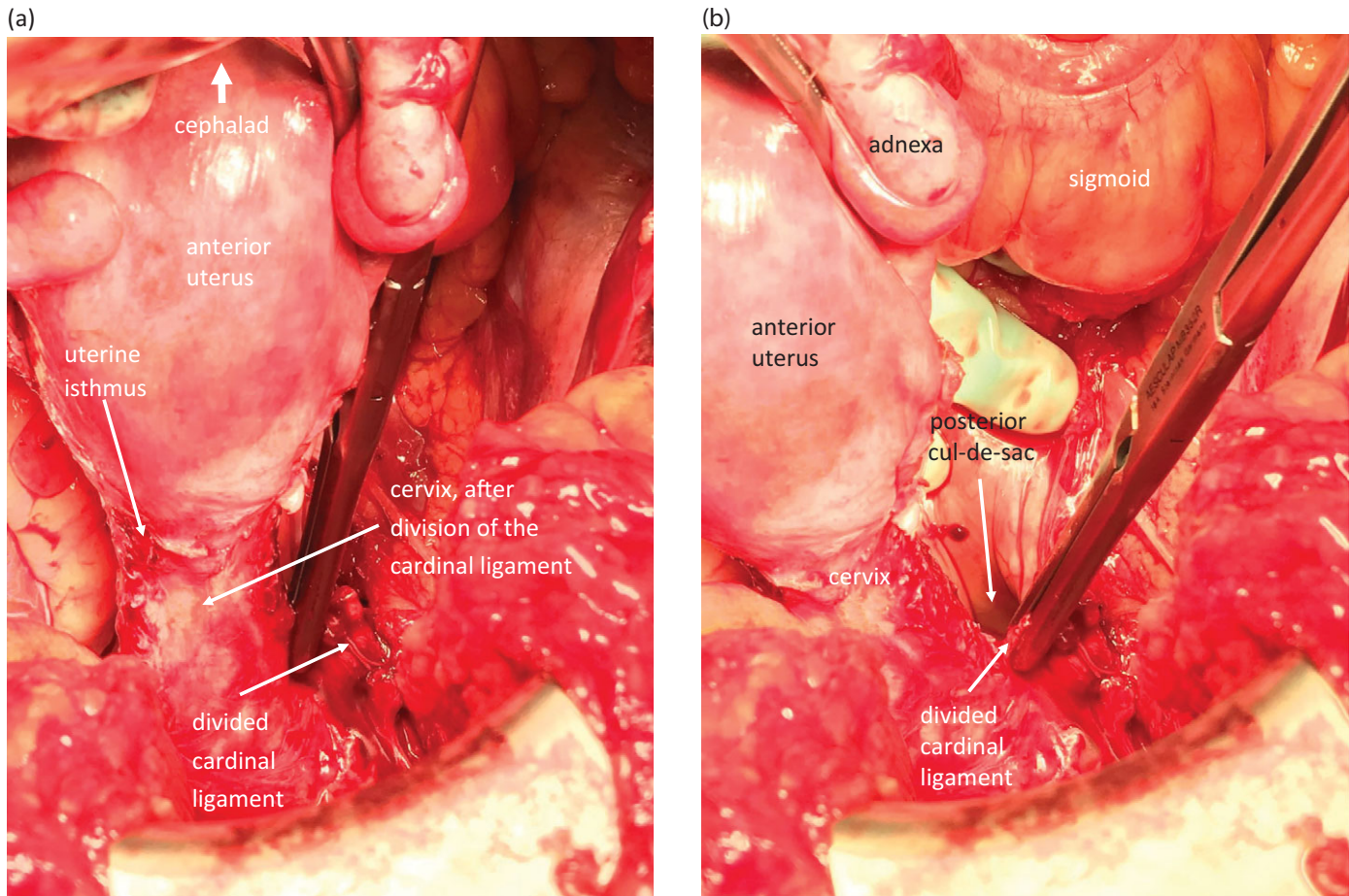


Figure 35.9 (a) Division of the cardinal ligament and mobilization of the cervix. (b) Cardinal ligament divided to the tip of the clamp prior to suture ligation in the same manner as the uterine artery.

- Divide the cardinal ligaments:
 - Using straight clamps (Haney or Zeppelin), the cardinal ligament is separated from the cervix.
 - Each clamp should be placed **medial** to the last pedicle to prevent ureteral compromise.
 - The clamps are situated vertically, then pulled laterally to a 30°–40° angle from the cervix as the clamp is closed. The clamps should be placed directly against the cervix such that the peritoneal and outer cervical fascia are pulled into the clamp around the cervical stroma as the clamps are closed, or such that they are “hugging the cervix.”
 - Using a curved mayo scissors, the tissue between the clamp and the cervix is divided to the tip of the clamp just until the tip falls free.
 - 0-vicryl suture is placed at the inferior medial tip of the clamp in the same fashion as with the uterine artery. Attention should be paid that the suture is tied down against the clamp so as not to incorporate more lateral tissue than is necessary.
- This process is continued, placing each subsequent clamp inside the prior pedicle, until the entire cardinal ligament has been separated from the cervix.
- The number of bites required will depend on the patient’s anatomy as there is a large heterogeneity between patients in cervical length and breadth.
- The cervix is palpated with the thumb anterior to the cervix and the forefinger posterior to the cervix (or vice versa) to determine where it meets the vagina. For a supracervical hysterectomy, the cervix can be divided after just the upper cardinal ligament is ligated. However, for a total hysterectomy, the cardinal ligament must be divided to the level of the cervicovaginal junction.
- If bleeding is encountered in this process, the best management is to continue with the subsequent bites and remove the uterus expeditiously. Subsequent bites usually will control bleeding.
- The bladder will need to be reassessed and further separated from the cervix, as needed during this process.

- Amputate the cervix from the vagina (TAH) or uterus from the cervix (SCH).
 - For a supracervical hysterectomy:
 - Once the cervix is encountered, it can be divided. Usually the upper cardinal ligament must be clamped and suture ligated 1–2 times before this point is reached. The uterus can be amputated from

the cervix using Bovie cautery just below the level of the uterine isthmus. After the specimen is removed, the remaining cervical stump is grasped with Kocher clamps and closed in figure-of-eight sutures for hemostasis. [Figure 35.3](#) shows where to amputate the cervix for SCH.

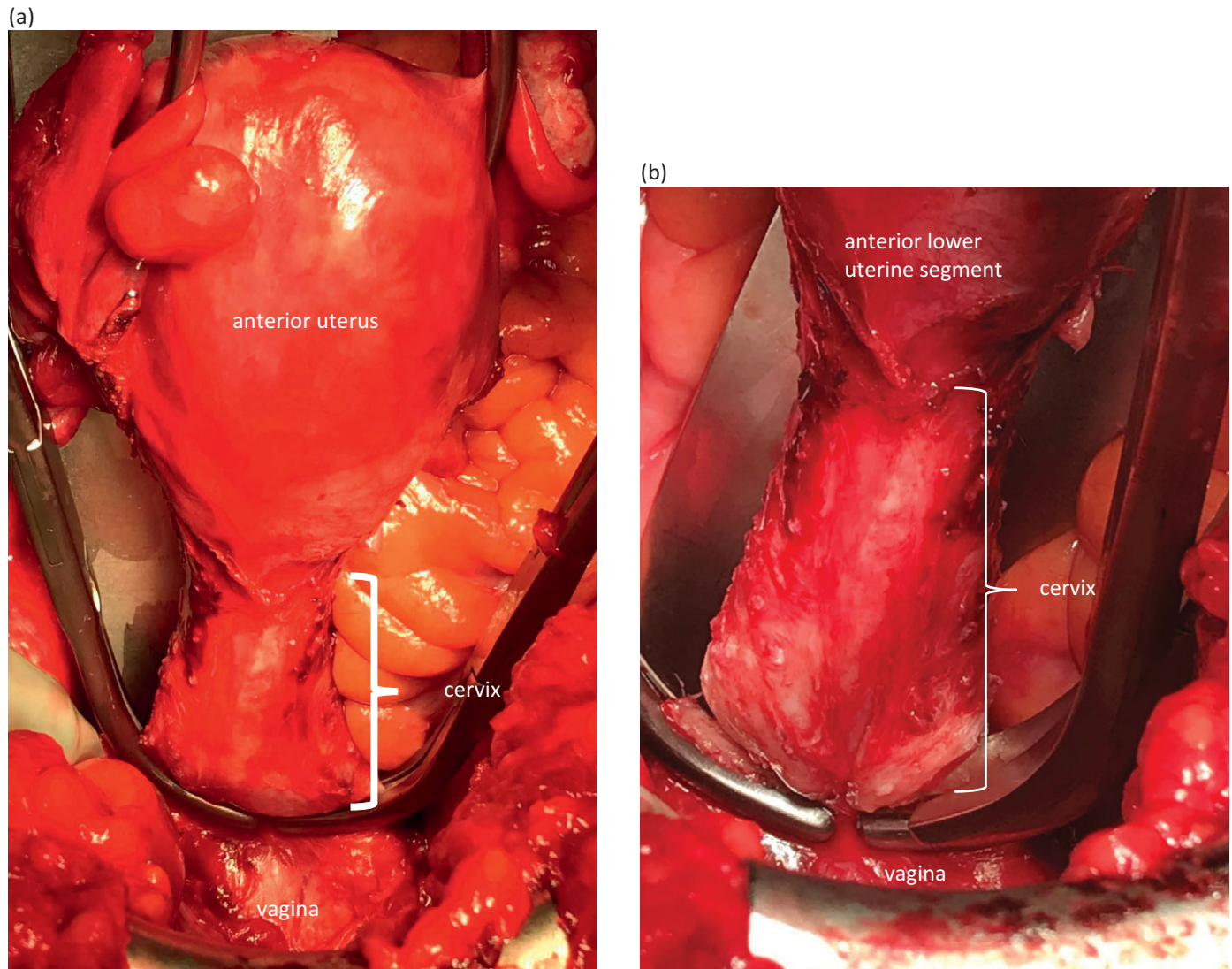


Figure 35.10 (a) Sharply curved Zeppelin forceps are placed under the cervix at the cervicovaginal junction. (b) The cervix is divided from the vagina using scissors.

- For a total hysterectomy:
 - Once the cardinal ligaments have been divided to the cervicovaginal junction, two sharply curved Zeppelin clamps are placed under the cervix (one from either side, with the tips meeting in the middle). They should be pulled upward as they are closed to hug the cervix so the vagina is not shortened in this process. Jorgenson scissors are used to amputate the specimen above the clamps.
 - A 0-vicryl stitch is placed in a figure-of-eight between the clamps and tied down. A second figure-of-eight suture is placed, starting with the first bite at the tip of the clamp and the second about 1 cm lateral, and held. A third fixation suture is placed to close the remaining lateral angle of the cuff just under the clamp. As the first knot is thrown, the clamp is removed and all sutures are pulled tight and the remaining knots thrown. Vaginal sutures can be left long until cuff hemostasis is ensured.
- The pelvis should then be irrigated with warmed sterile water to check for hemostasis.
 - Hemostasis can be achieved with Bovie cautery or suture ligation. Avoid deep lateral suture ligation, which can cause bleeding and/or incorporate the ureter.
- The myometrium bleeds easily, so use cautery judiciously. For minor bleeding, use pressure, work on something else, and come back later to check on it.
- Hysterectomy during (gravid hysterectomy) or immediately after (cesarean-hysterectomy) pregnancy requires careful dissection of much larger vascular pedicles than in the nongravid state. The steps are the same, but the pedicles may need to be separated into smaller segments by dissection along avascular planes and ligated serially. Using LigaSure alone on these pedicles is inadvisable. Identifying the end of the cervix is difficult, and due to penchant for causing additional bleeding with total hysterectomy, supracervical hysterectomy is preferable in this setting.
- Remember that the bladder shares a peritoneal surface with the lower uterine segment and is at risk of damage, if not properly dissected off of the uterus and cervix.
- The uterus and cervix can be very deep in the pelvis. Ensure adequate exposure to the pelvis by extending the fascial incision to the pubic symphysis. Using a good self-retaining retractor also facilitates exposure.
- The two most common locations of ureteral injury during hysterectomy occur at the cardinal ligament during ligation of the uterine vessels and during ligation of the uterine vessels with removal of the ovaries. At the ovarian vessels, it is important to identify the ureter to avoid injury. At the level of the uterine vessels, adequate visualization and dissection of the vessels and mobilization of the bladder off of the uterus and cervix prior to ligation of the uterine artery prevents ureteral injury.

Tips and Pitfalls

- When deciding on salvage or removal of the adnexal structures, remember to consider the patient's age, and hormonal/fertility needs.

Damage Control for Pelvic Fracture Bleeding

Kazuhide Matsushima, Bryan Love, and Mathew D. Tadlock

Surgical Anatomy

- Severe bleeding in complex pelvic fractures usually originates from branches of the internal iliac artery, presacral venous plexus, fractured bones, and soft tissues. Major iliac vascular injuries are encountered in about 10% of patients with severe pelvic fracture.
- The abdominal aorta bifurcates into the two common iliac arteries at the L4-L5 level. The iliac veins are located posterior and to the right of the common iliac arteries. The ureter crosses over the bifurcation of the common iliac artery as it branches into the external and internal iliac arteries.
- The internal iliac artery is about 4 cm long. At the level of the greater sciatic foramen, it divides into the anterior and posterior trunks. It supplies numerous splanchnic and muscular branches and terminates as the internal pudendal artery, which is a potential source of hemorrhage in anterior ring disruptions. Hemorrhage following pelvic fracture can occur from any branch.
- The most commonly injured internal iliac artery branches (in decreasing order of frequency) are the superior gluteal, internal pudendal, and obturator arteries.
 - The superior gluteal artery is the largest branch of the internal iliac artery. It exits the pelvis through the greater sciatic foramen above the piriformis muscle. It provides blood supply to gluteus medius and minimus muscles.
 - The internal pudendal artery passes through the greater sciatic foramen, courses around the sciatic spine, and enters the perineum through the lesser sciatic foramen.
 - The obturator artery courses along the lateral pelvic wall and exits the pelvis through the obturator canal. In 30% of cases, the obturator artery is perfused from both internal and external iliac arteries, making angioembolization more complicated.

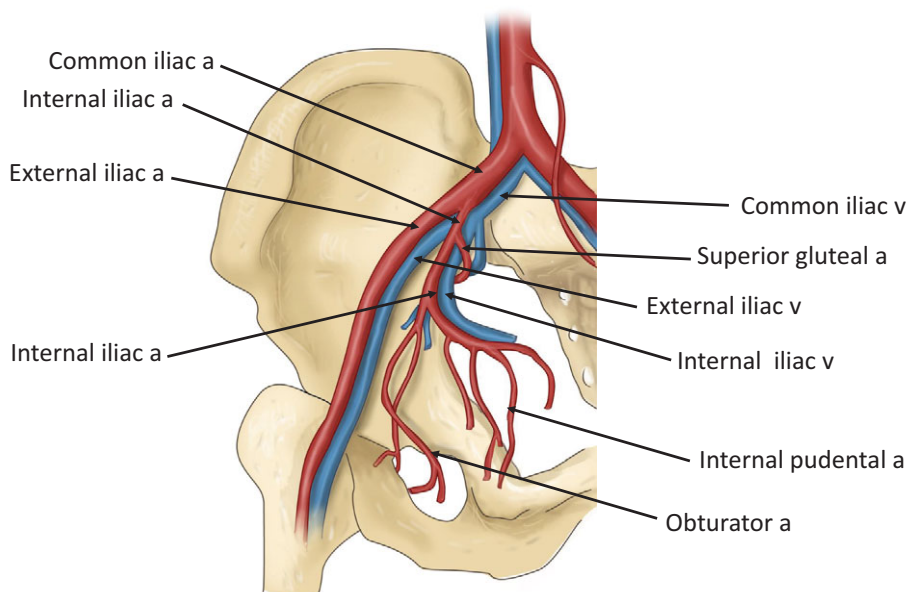


Figure 36.1 Anatomy of the iliac vessels. The most commonly injured internal iliac artery branches (in decreasing order of frequency) are the superior gluteal, internal pudendal, and obturator arteries.

General Principles

- Any significant (>3 cm) pubic symphysis diastasis significantly increases the pelvic volume and reduces the effectiveness of tamponade of venous bleeding.
- Complex pelvic fractures are associated with a high incidence of intra-abdominal injuries and significant blood loss. Nearly 30% of these fractures are associated with intra-abdominal injuries and 80% have multisystem trauma.
- The most commonly associated intra-abdominal injuries involved the bladder and urethra, followed by the liver, small bowel, spleen, and diaphragm.
- Patients with severe pelvic fractures should be admitted to the intensive care unit under general or trauma surgery for close monitoring for major bleeding or possible intra-abdominal injuries, for at least 24 hours, before transferring to an orthopedic service.
- The hemorrhage in pelvic fractures originates from the fractured bone surfaces, pelvic venous plexus, the internal iliac artery branches (15–20%), and soft tissue injuries. Pelvic vascular injuries involving the major iliac veins and arteries occur in about 10% of severe fractures.
- Independent predictors of severe hemorrhage from pelvic fractures include persistent hypotension, contrast extravasation on CT imaging, large pelvic sidewall hematoma, sacroiliac joint disruption, pubic symphysis diastasis >2.5 cm, bilateral and concomitant superior and inferior pubic rami fractures (“Butterfly fracture”), age ≥ 55 years, and female gender.
- While the anteroposterior compression (i.e. open book pelvic) fractures are frequently associated with pelvic vascular injury and hemodynamic compromise, lateral compression fractures are often associated with injuries to the urogenital and the gastrointestinal structures.
- A pelvic radiograph is useful in determining the need for or contraindication to application of a pelvic binder; pubic symphysis diastasis is an excellent indication for pelvic binder application, while a fracture of the iliac wing, severe acetabular fractures, and generally lateral compression fractures are contraindications because they might worsen the fracture displacement, pain and, perhaps, bleeding. However, a pelvic radiograph often underestimates the severity of the fracture and may miss posterior fractures.
- Avoid intravenous access in the groin because of the possibility of an associated iliac venous injury.

Management of Pelvic Fracture Bleeding

- The majority of patients with bleeding from pelvic fractures can safely be managed with supportive measures, such as pelvic immobilization and blood transfusions, while some require angioembolization. The massive transfusion protocol should be followed in the appropriate cases.
- Pelvic binder is the first treatment to reduce the pelvic ring volume in open book pelvic fractures. The pelvic binder should be applied over the major trochanters to allow laparotomy and femoral artery access for catheter-based angiographic embolization.
- Pelvic binder is contraindicated in major iliac wing fractures, complex acetabular fractures, and lateral compression fractures.

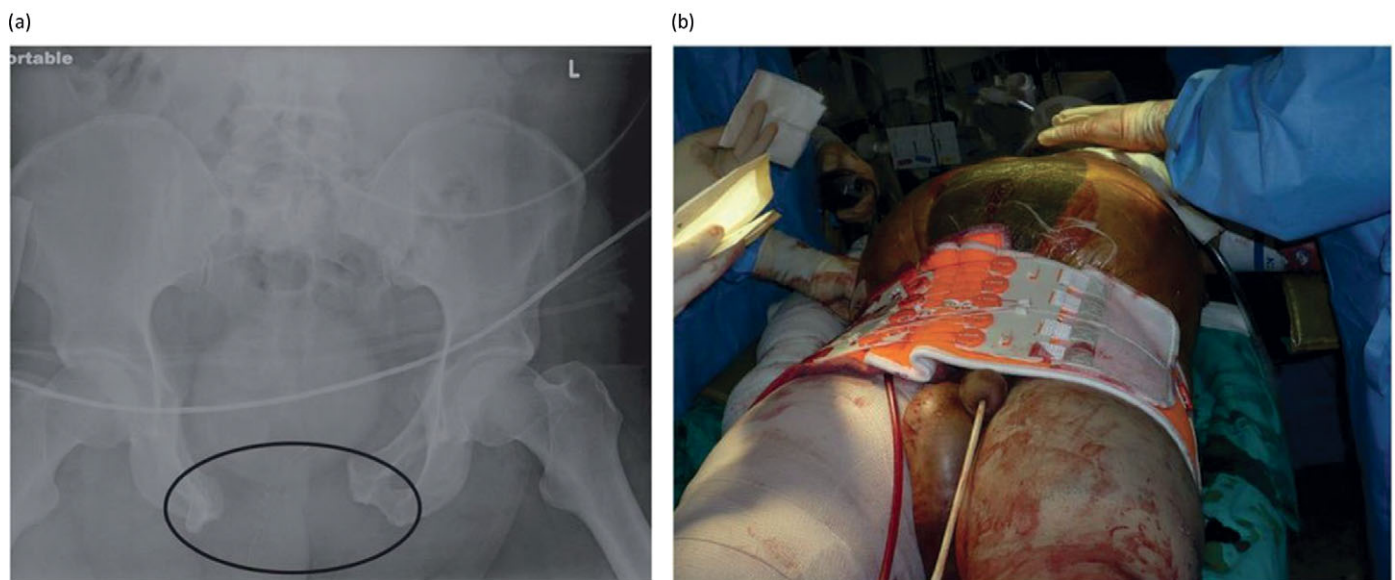


Figure 36.2 Open book fracture with significant pubic symphysis diastasis (a). A pelvic binder is useful in reducing and stabilizing this type of fractures (b). Contraindications for pelvic binder application: (c) Fractures of the iliac wing (white circle), severe acetabular fracture (red circle) is contraindicated in lateral compression fractures and pubic rami fractures, as it may worsen bleeding. (d) Lateral impact injury with severe acetabular fracture (white circle).

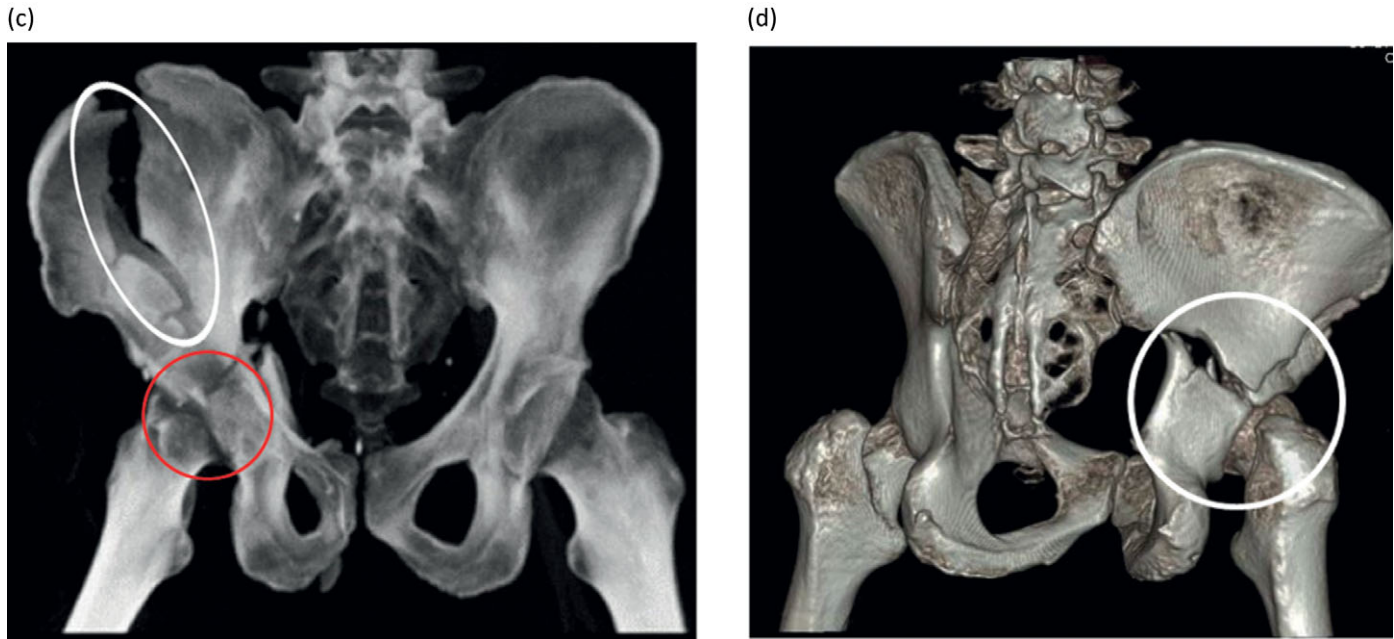


Figure 36.2 (cont.)

- External pelvic fixation in the emergency room is rarely indicated or performed and there is no evidence that it is of any benefit.
- In a small number of patients with severe bleeding not responding to conventional therapeutic interventions, damage control with pelvic packing may be life-saving. The indications for operative management include severe hemodynamic instability, need for laparotomy for associated intra-abdominal injuries, and failed or nonavailability of angioembolization.
- Selected patients with severe pelvic fracture bleeding may benefit from a REBOA balloon deployment in zone 3.

Damage Control Operations

There are three methods of damage control in severe pelvic fracture bleeding: The extra-peritoneal packing approach, the USC intraperitoneal packing approach, and REBOA balloon catheter aortic occlusion.

Special Requirements

- In selected cases, the optimal setting is the hybrid operating room with both surgical and interventional radiology capabilities simultaneously available.

- REBOA may be placed in the emergency room, operating room, or ICU.
- Major trauma laparotomy tray and vascular tray must be available.
- Large and medium clips and appliers.
- Vessel loops.
- Local hemostatic sealants based on fibrin, thrombin, collagen sponge, cellulose, microfibrillar collagen, and bone wax facilitate local hemostasis and effective packing.
- Angiography equipment with embolization coils and Gelfoam particles.

Patient Positioning

- The patient is positioned in the supine position for trauma laparotomy and resuscitative thoracotomy when warranted. Skin preparation should include the chest, abdomen, and lower extremities to the knees.
- Access to the femoral artery below the inguinal ligament should be available for interventional radiology.

Extra-Peritoneal Pelvic Packing

- An 8–10 cm skin incision is made in the midline below the umbilicus.

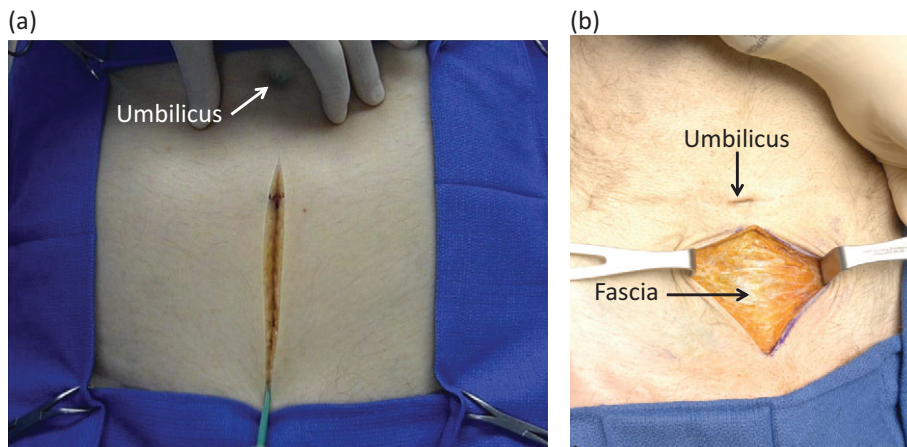


Figure 36.3 A 6–8 cm skin incision is made at the midline, below the umbilicus (a) and the midline fascia is exposed.

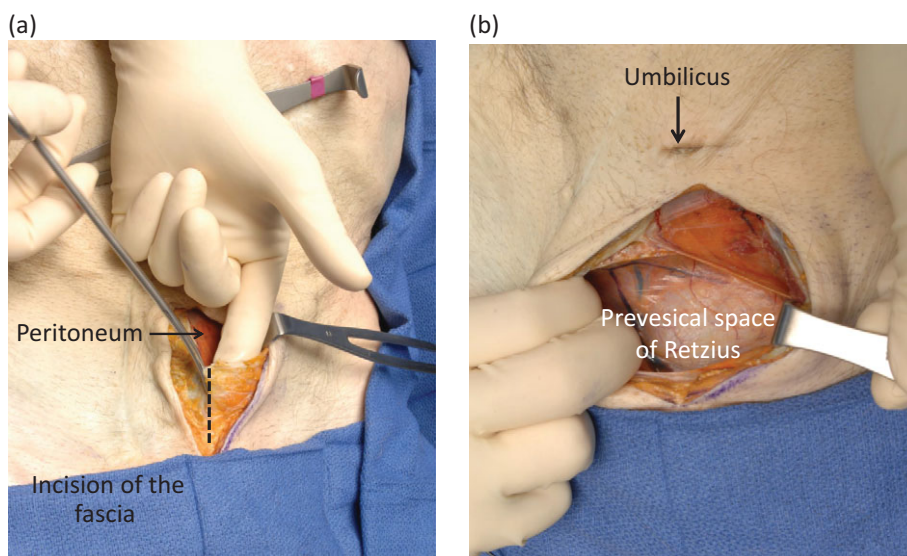


Figure 36.4 The midline fascia is exposed and incised down to the peritoneum (interrupted line). The peritoneum is exposed but not entered (a). The prevesical space of Retzius is exposed (b).

- The midline fascia is exposed and incised down to the peritoneum. The peritoneum is not entered. The prevesical space of Retzius is now exposed.
- Any clots are removed from the prevesical space, and the bladder and peritoneum are swept medially to allow for effective packing.
- Three laparotomy packs are inserted extraperitoneally along the pelvic sidewall on both sides of the bladder, towards the sacroiliac joint and internal iliac vessels, to control bleeding originating from internal iliac arteries and vein plexuses.

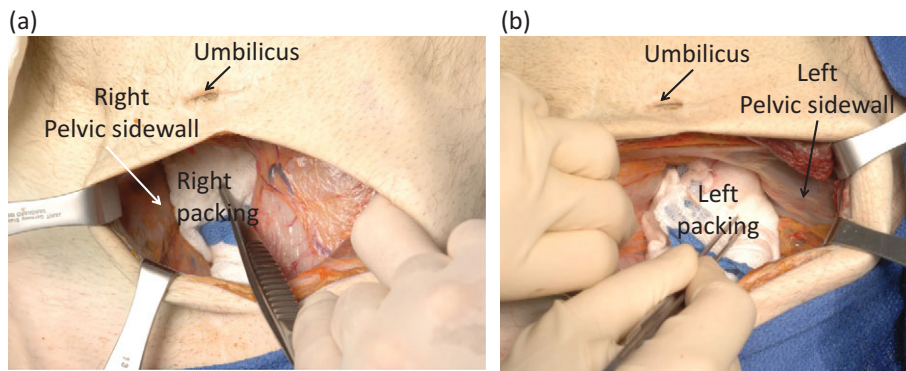


Figure 36.5 (a, b) The peritoneum and the bladder are reflected posteromedially for extraperitoneal pelvic packing. Packs are placed posteriorly towards the sacroiliac joint and internal iliac vessels. Three packs are placed on each pelvic sidewall.

- Following the packing, the rectus sheath is closed with running suture to facilitate effective tamponade.
- Early angiography should be considered after the extraperitoneal packing.

The USC Approach of Intraperitoneal Packing Damage Control

- Rationale for intraperitoneal damage control: Exploration and management of associated abdominal injuries, direct evaluation of major iliac vessels and areas of bleeding, direct gauze packing of the bleeding area, and occlusion of both the internal iliac arteries.
- A formal exploratory trauma laparotomy is performed. Any associated intraperitoneal injuries are identified and treated.
- The retroperitoneum may be opened directly with an incision over the hematoma in the midline, below the bifurcation of the aorta into the iliac arteries. Alternatively, the hematoma and iliac vessels may be explored after medial mobilization of the sigmoid colon or the right colon. The hematoma is evacuated, and any obvious major bleeding from the large vessels is controlled with sutures, ligation, or repair.

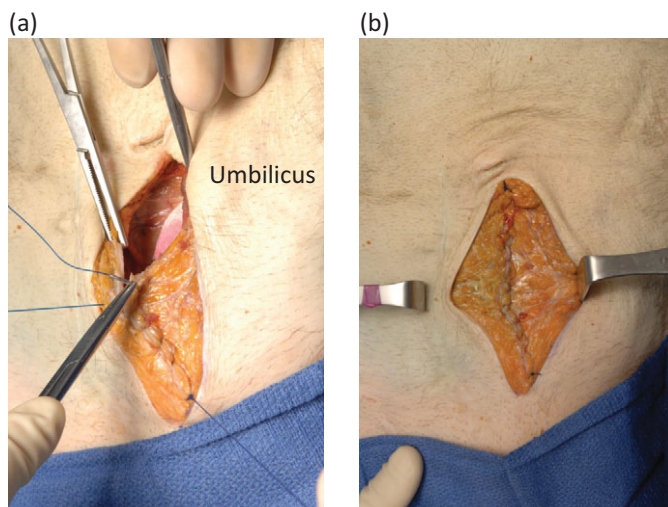


Figure 36.6 (a, b) The fascia is closed over the extraperitoneal pelvic packing.

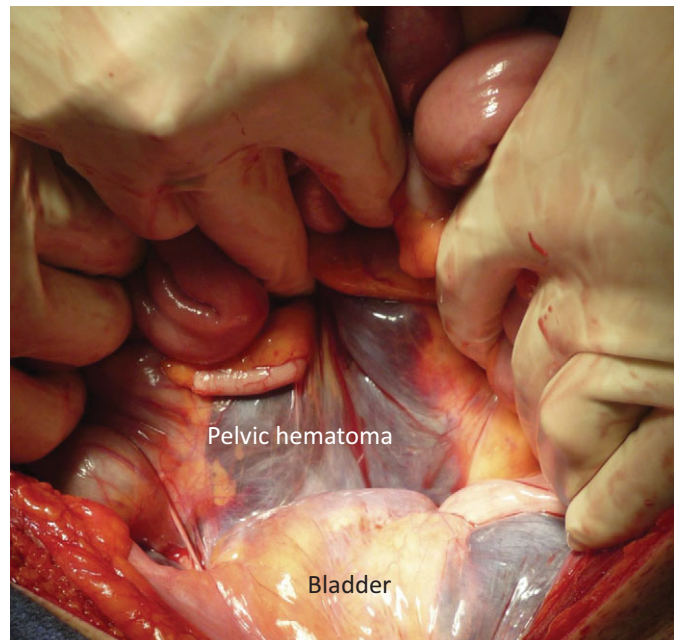


Figure 36.7 Pelvic hematoma associated with a pelvic fracture. The hematoma can be opened with a direct incision over the hematoma in the midline, below the bifurcation of the aorta. Alternatively, the hematoma and iliac vessels may be explored after medial mobilization of the sigmoid colon or the right colon.

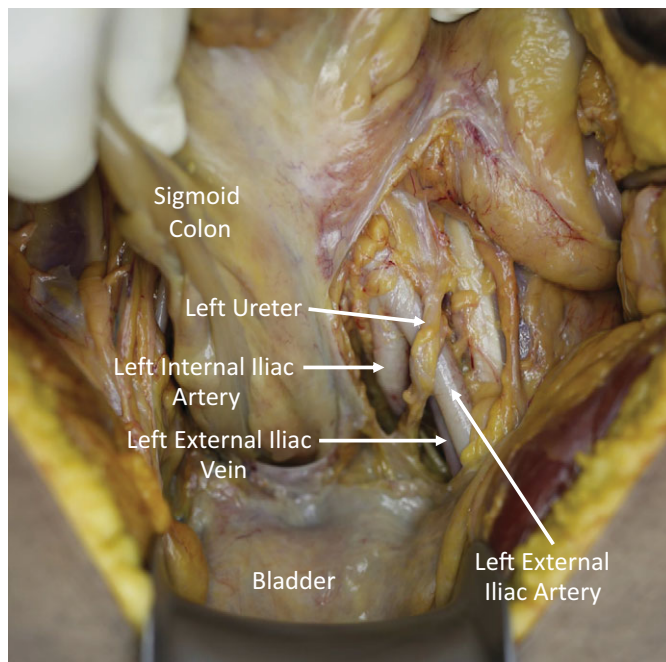


Figure 36.8 The sigmoid colon is mobilized and reflected medially and the retroperitoneum is opened, exposing the left external and internal iliac arteries. The left external iliac vein is seen posterior and medial to the left external iliac artery. Note the ureter crossing over the bifurcation of common the iliac artery.

- The common iliac arteries are dissected bilaterally, and the internal iliac arteries are identified and isolated using right-angle clamps.
- Care must be taken to avoid injury to the ureters, which cross over the bifurcation of the common iliac artery into the external and internal iliac arteries.
- Vessel loops are applied to both internal iliac arteries and firm retraction is applied to occlude the pelvic arterial inflow.

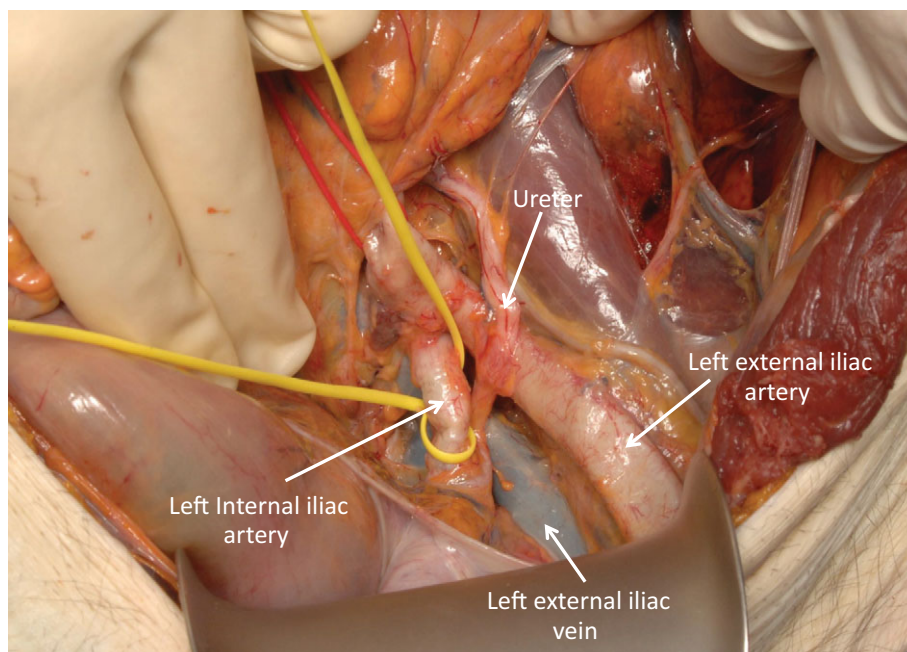
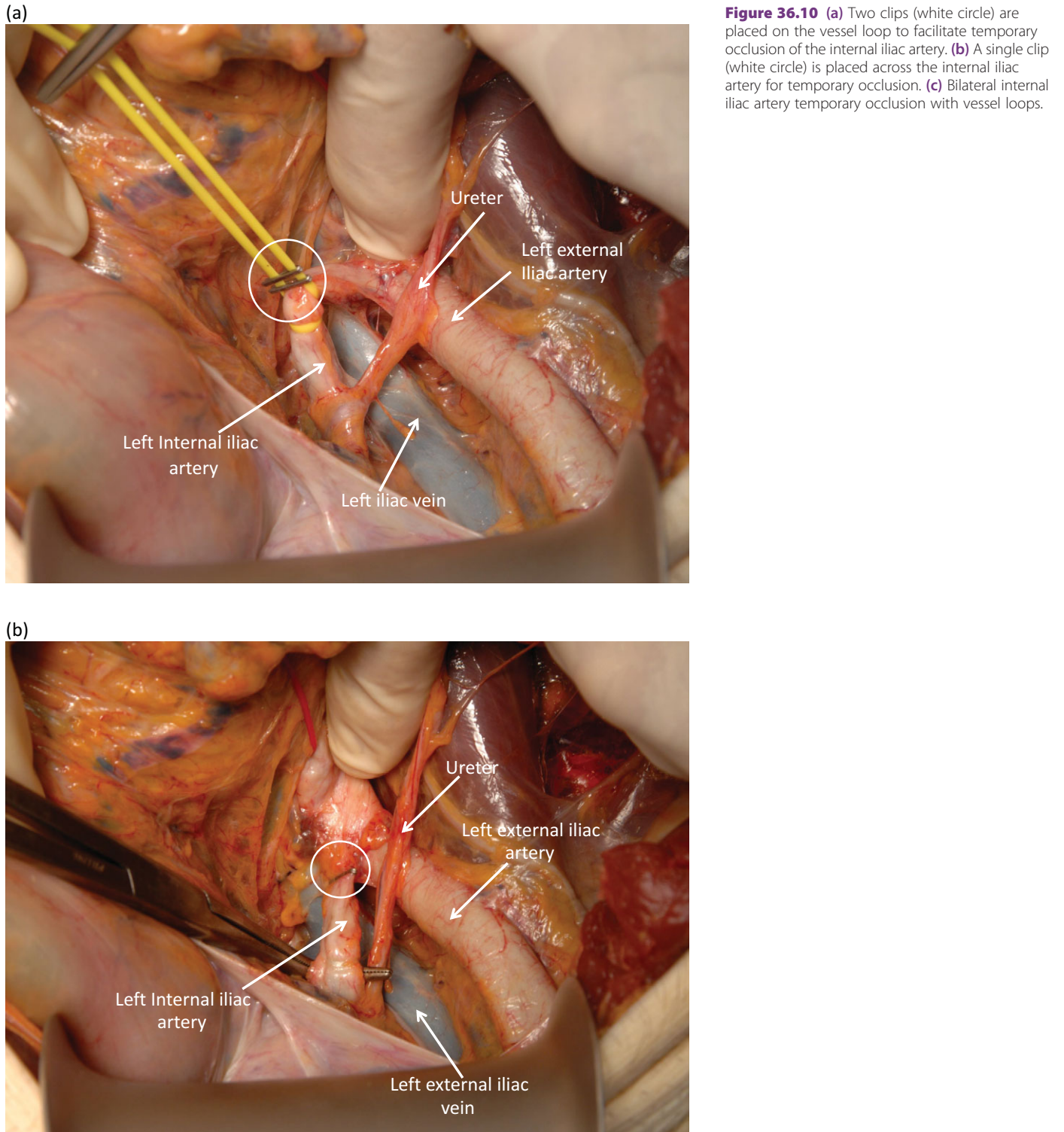


Figure 36.9 The internal iliac arteries are isolated with vessel loops. Note the ureter crossing over the external iliac artery.

- Surgical clips are placed on the retracted vessel loops to facilitate the temporary vessel-loop-clip occlusion of the internal iliac artery. The procedure is performed bilaterally for effective inflow occlusion.
- The use of the vessel-loop-clip occlusion technique allows vessel loop removal in the subsequent angiography setting for embolization following the surgical damage control.
- Alternatively, the internal iliac arteries can be bilaterally occluded using surgical clips. Surgical clip placement allows clip removal and angioembolization in the postoperative phase of care, when warranted.



(c)

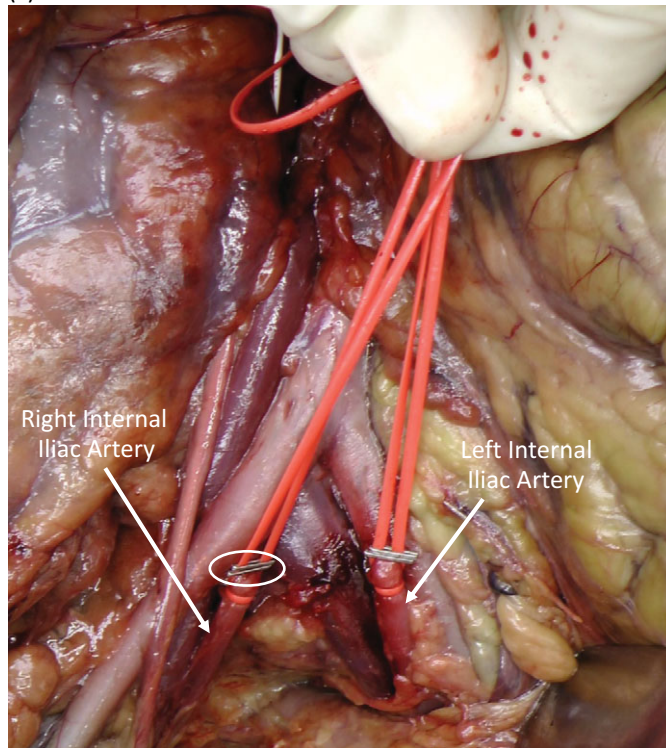


Figure 36.10 (cont.)

- Following vascular control and application of local hemostatic sealants, pelvic packing is performed and temporary abdominal closure is performed, using a negative pressure system (see [Chapter 23](#) Damage Control Surgery)
- Catheter-based angiography of the aorta, lumbar arteries, and the external iliac branches should be considered in the appropriate cases.

REBOA Balloon Catheter Aortic Occlusion

- Hemodynamically unstable patients may benefit from REBOA balloon deployment in the abdominal aorta, just above the bifurcation into the iliac arteries (Zone 3) (see [Chapter 24](#) on REBOA)

Tips and Pitfalls

- In the presence of a pelvic hematoma, the FAST exam may be unreliable in the diagnosis of intra-abdominal hemorrhage. If the patient's condition allows, CT scan evaluation is indicated. If this is not possible, consider open Diagnostic Peritoneal Aspirate (DPA).
- Activate massive transfusion protocol early in the management of the hemodynamically compromised patient.
- Remember the high incidence of associated intra-abdominal injuries.
- Extraperitoneal packing without abdominal exploration may miss significant intra-abdominal injuries.
- In the appropriate cases, consider deploying a REBOA balloon catheter in the abdominal aorta, Zone 3.
- Severely hemodynamically compromised patients should be taken to the operating room, ideally the hybrid suite, for abdominal exploration for associated injuries, possible damage control in the pelvis, and angioembolization.
- Avoid ligation of the internal iliac artery in cases with acetabular fractures because it may interfere with subsequent surgical exposure and repair of the fracture. Temporary occlusion of the vessels prevents this problem.
- Inadequate knowledge of the anatomy of the iliac vessels and their relationship to the ureter may result in iatrogenic injury to the ureter or the iliac veins.

Brachial Artery Injury

Peep Talving and Elizabeth R. Benjamin

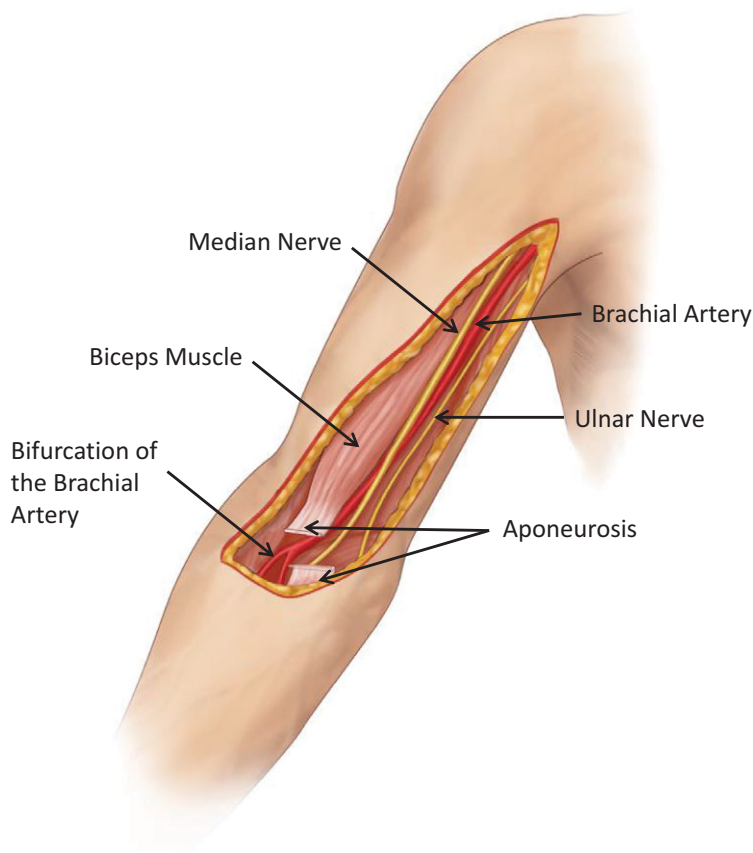
Surgical Anatomy

- The brachial artery lies in the groove between the biceps and triceps muscles. The proximal brachial artery lies medial to the humerus and moves anterior as it progresses distally. At the antecubital fossa, it runs under the aponeurosis of the biceps muscle and typically bifurcates just below the elbow into the radial and ulnar arteries (Figure 37.1).
- The brachial artery is surrounded by two concomitant brachial veins, which run on either side of the artery. At the

upper part of the arm, their confluence forms the axillary vein.

- The profunda brachial artery is a large branch that arises from the proximal third of the brachial artery and communicates with collateral circulation to the lower arm (Figure 37.2). Due to these collaterals, the lower arm may have adequate perfusion despite injury to the distal two thirds of the brachial artery.

Figure 37.1 The brachial artery lies in the groove between the biceps and triceps muscles. Note the close anatomical relationship with the median and ulnar nerves. In the upper arm, the median nerve is anterolateral to the artery and at the middle it crosses over to course posteromedial to the artery. The artery bifurcates into the ulnar and radial arteries under the bicipital aponeurosis, at the antecubital fossa.



(a)

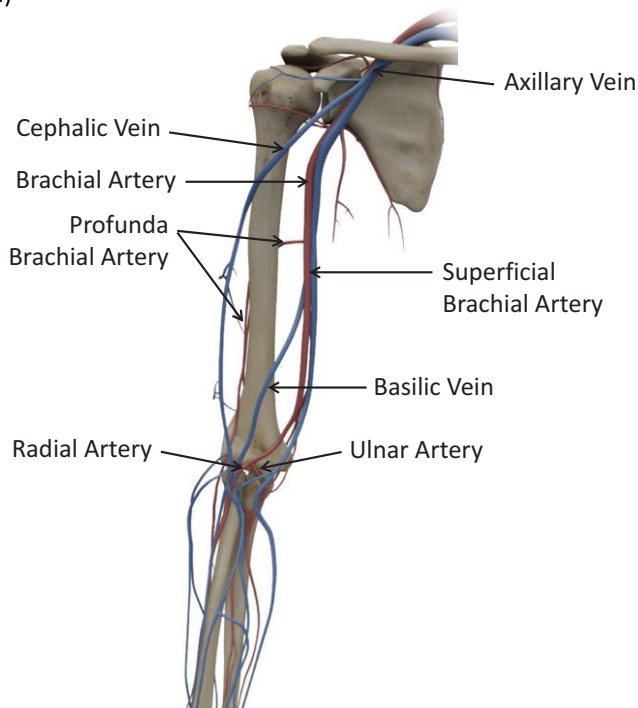
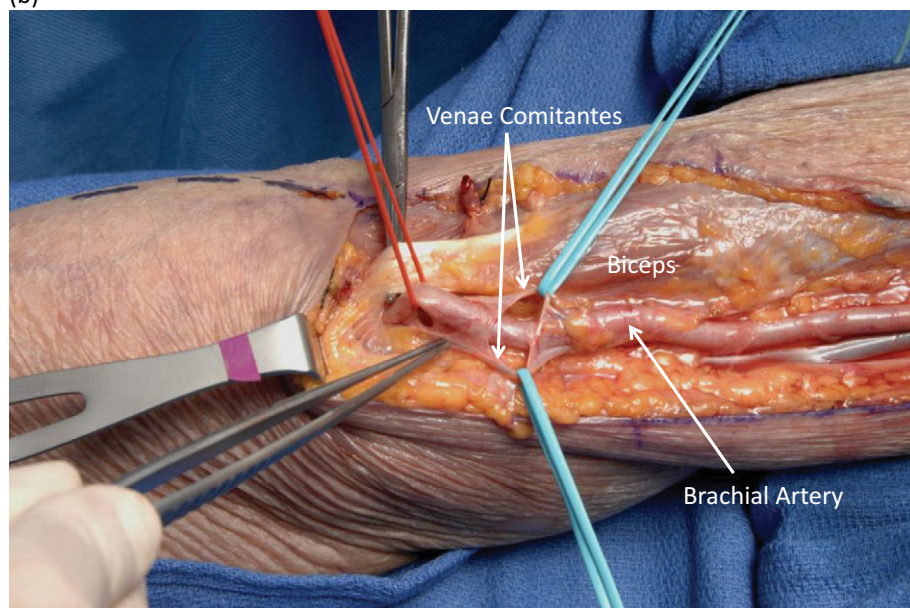


Figure 37.2 (a) Anatomy of the major branches of the brachial artery and the superficial and deep veins of the arm. **(b)** Paired brachial veins run on either side of the brachial artery.

(b)



- The basilic vein courses in the subcutaneous tissue in the medial aspect of the lower arm. At the mid arm, it penetrates the fascia to join one of the brachial veins.
- The cephalic vein is entirely in the subcutaneous tissues, courses in the deltopectoral groove, and joins the junction of the brachial and axillary veins.
- In the upper arm, the median nerve courses anterolateral to the brachial artery. It then crosses over the artery and lies posteromedial to the brachial artery as they pass under the aponeurosis of the biceps muscle.
- In the upper half of the arm, the ulnar nerve lies posterior to the brachial artery. In the mid arm, the nerve pierces the intermuscular septum and courses posteriorly away from the artery, behind the medial epicondyle.

General Principles

- Almost all significant vascular injuries are diagnosed based on clinical examination.
- “Hard signs” of vascular injury include pulsatile bleeding, an expanding or pulsatile hematoma, a palpable thrill, audible bruit, absent or very diminished peripheral pulse, and/or distal ischemia. These signs are strong indications for immediate operative exploration. Patients with blunt trauma or shotgun injuries with multiple pellets may benefit from preoperative CT or formal angiography.
- “Soft signs” of vascular injury include minor bleeding, stable small hematomas, and an ankle-brachial index (ABI) less than 0.9. In these cases, arterial evaluation by duplex or CT angiogram should be performed.
- Hemorrhage from the brachial artery can be temporarily controlled using direct digital compression or a proximal tourniquet.
- Ligation of the brachial artery is associated with a high incidence of limb loss and should not be performed. In patients in extremis, a temporary shunt and delayed reconstruction should be considered.
- In the event of a mangled extremity, flow is established with a temporary shunt, followed by wound debridement, external fixation of the fracture, and finally, delayed definitive vascular repair.
- Brachial artery injuries can be managed with primary repair or autologous vein graft reconstruction. In general, synthetic grafts should be avoided for arterial reconstruction below the shoulder because of poor long-term patency rates.
- Completion angiogram should be considered if there is any concern regarding distal flow.
- Patients with brachial artery injuries, especially those with prolonged ischemia or associated venous injuries, should be monitored for compartment syndrome with serial clinical examinations, compartment pressure monitoring, and serial blood creatine kinase (CK) levels. Fasciotomy should be considered in appropriate cases.
- Routine prophylactic fasciotomy is not indicated and may increase morbidity.

Special Surgical Instruments

- A vascular tray.
- A sterile tourniquet should be in the field for proximal control.
- A sterile ultrasound probe should be available for perfusion monitoring and saphenous vein mapping.
- Fogarty catheters: 3 F should be available for thrombectomy.
- Heparin solution: 5,000 units of heparin in 100 mL of normal saline for regional heparinization after clot clearance.
- An array of shunt sizes should be available to restore blood flow in case immediate repair or reconstruction is not possible. Argyle shunts ranging from 8 to 14 F should be adequate for most injuries.
- If an angiogram is to be performed, fluoroscopy, an 18G butterfly needle, and water-soluble contrast should be available.

Positioning

- The patient is positioned in the supine position with the injured arm abducted 90°, externally rotated to face palm up on an arm table board. Skin preparation should include the hand, circumferential arm to the axilla, shoulder, neck, and chest. The patient’s prepped hand should be covered with a sterile stockinette or blue towel.
- Potential operative needs to be considered during skin preparation include access to the wrist and hand for perfusion monitoring, forearm for compartment pressure monitoring, and the axilla and chest for emergent proximal vascular control.
- The bilateral groins should be prepared for possible vein harvest.

Incision

- The skin incision to expose the brachial artery is made between the biceps and triceps brachii ([Figure 37.3a, b](#)). This incision can be extended proximally to the deltopectoral groove for axillary artery exposure, or distally, curving towards the radius in the antecubital fossa to expose the brachial bifurcation. The basilic vein is identified and protected in the subcutaneous tissue in the lower part of the arm.

(a)

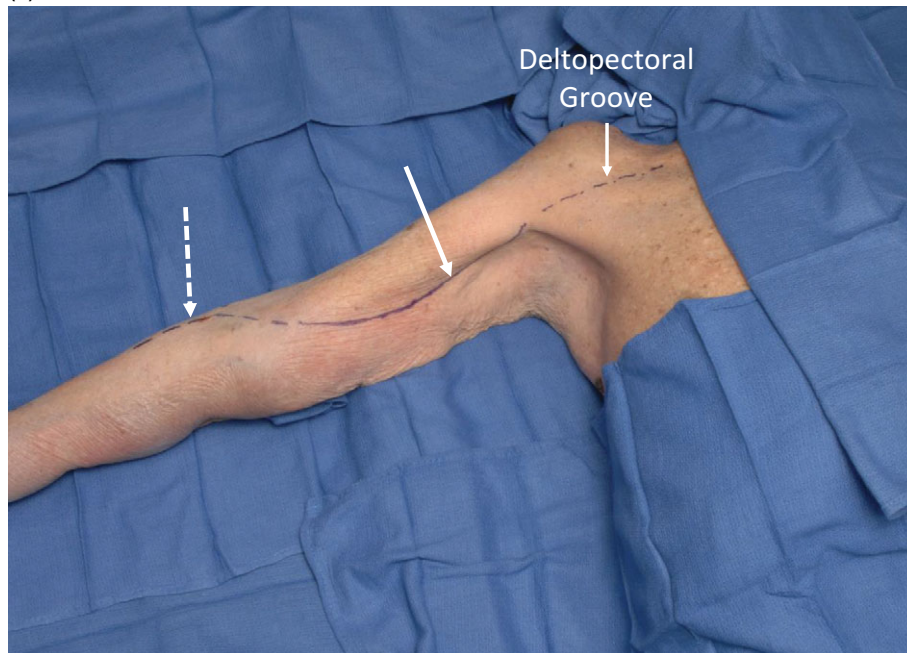


Figure 37.3 (a, b) The skin incision for brachial artery exposure extends proximally from the deltopectoral groove, along the groove between the biceps and triceps muscles (solid red arrow), curving radially over the antecubital fossa. For more proximal control at the axillary artery level, the incision is extended into the deltopectoral groove. The incision can be extended distally curving towards the radius in the antecubital fossa to expose the brachial bifurcation (dotted white arrow).

(b)



Exposure

- Access to the brachial artery requires anterior retraction of the biceps and posterior retraction of the triceps muscles in order to expose the neurovascular structures (Figure 37.4a).

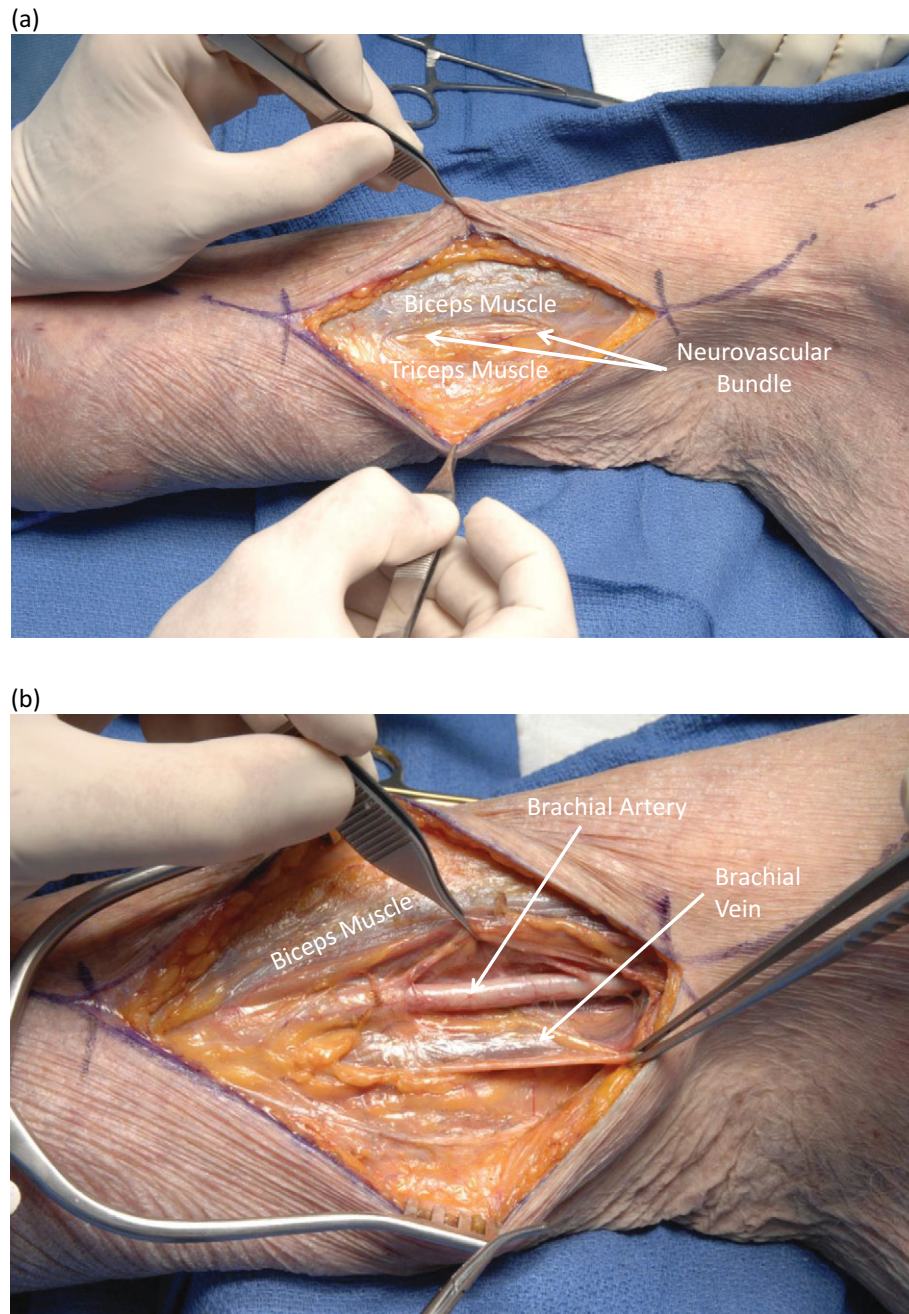


Figure 37.4 (a) The neurovascular bundle runs between the biceps and triceps brachii muscles, under the fascia. (b) Exposed neurovascular bundle behind the retracted biceps muscle.

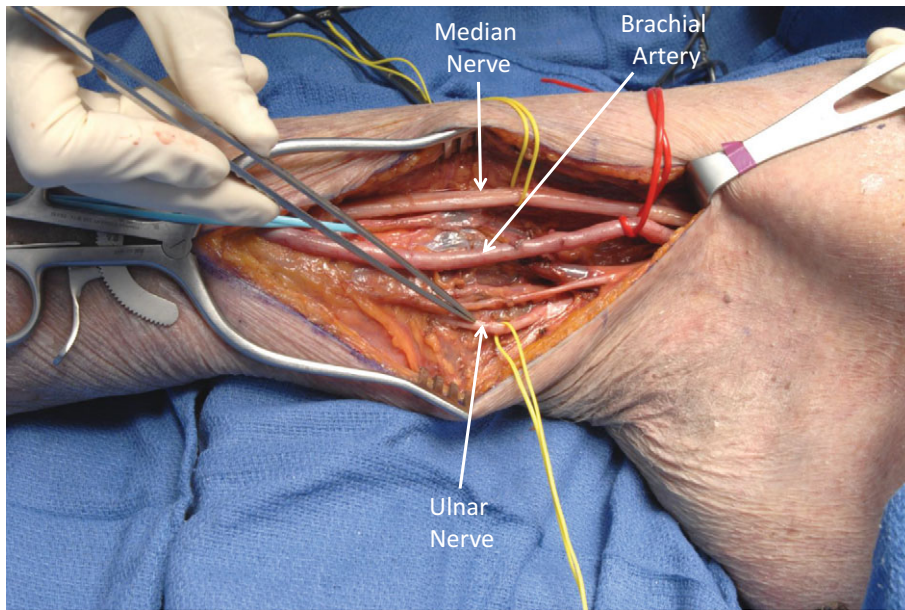


Figure 37.5 Exposure of the right brachial artery. The median nerve is anterolaterally and the ulnar nerve posteromedially. The ulnar nerve courses posteriorly.

- The brachial artery is covered by a fascial sheath within the groove between the biceps and triceps muscles (Figure 37.4b).
- In the proximal arm, the brachial artery lies just posterior and medial to the median nerve and anterior and lateral to the ulnar nerve (Figure 37.5). The basilic vein lies medial, outside the brachial artery sheath. Once the muscle bellies are retracted, the ulnar nerve and basilic vein should fall posteriorly with the triceps muscle and out of the operating field.
- The profunda brachial artery branches off the brachial artery in the proximal third of the upper arm and is accompanied by the radial nerve (Figure 37.6). It is important to preserve this branch if not injured, as it provides collateral circulation to the lower arm.

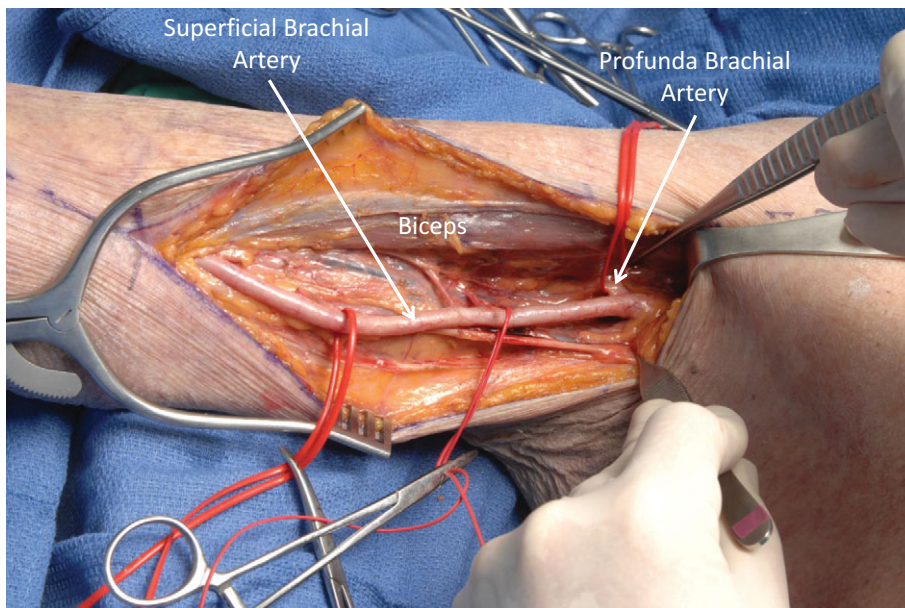
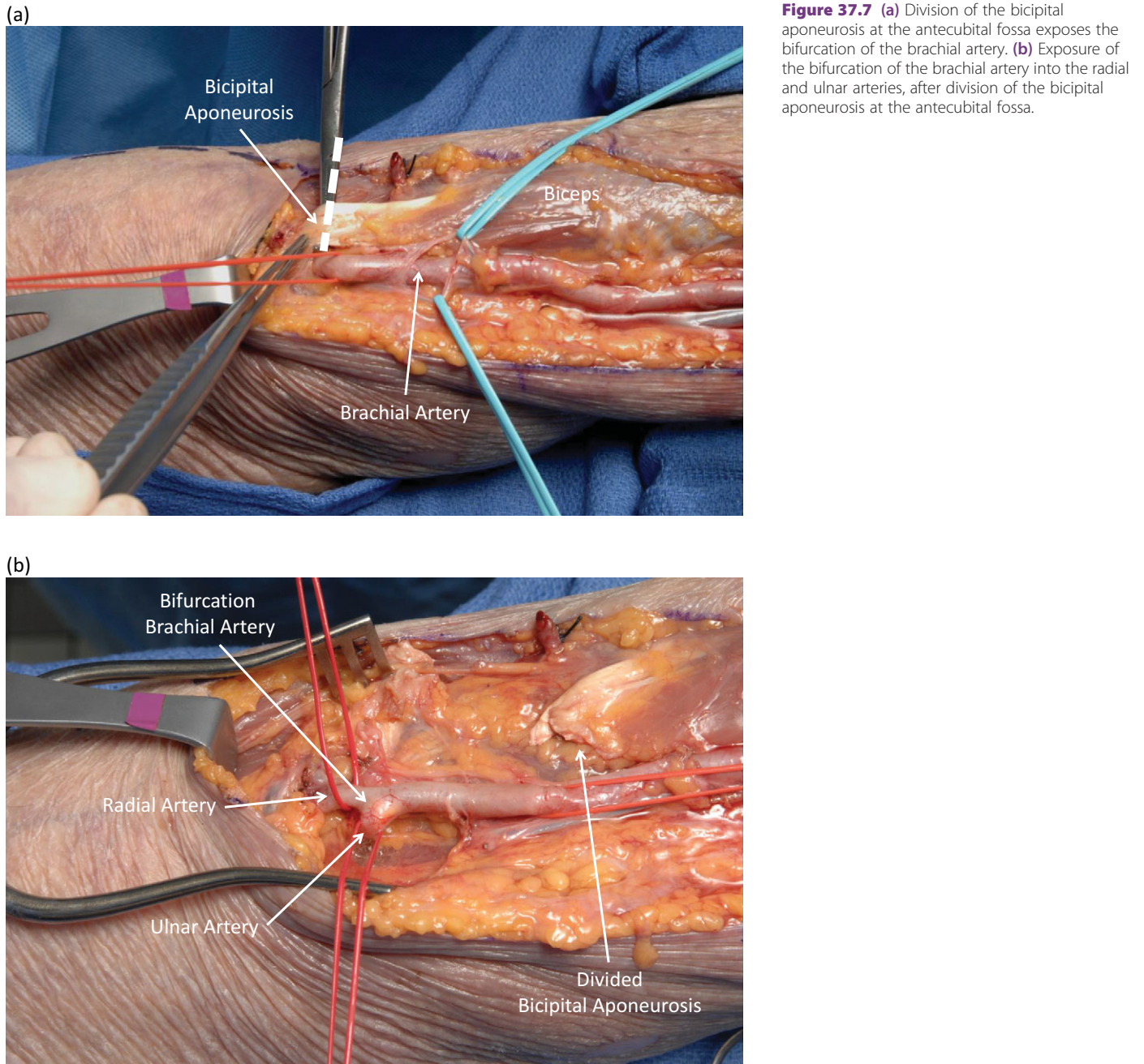


Figure 37.6 The proximal brachial artery gives off a profunda branch. This branch should be preserved, whenever possible, because it may provide important collateral circulation to the lower arm.

- In the lower part of the arm, the median nerve crosses over the brachial artery and then courses medial to the artery, as the artery bifurcates into the radial and ulnar arteries at the antecubital fossa.
- In order to access the brachial artery bifurcation, the aponeurosis of the biceps muscle should be divided (Figure 37.7a, b). Division of this aponeurosis has no clinical consequence and it does not require reconstruction.



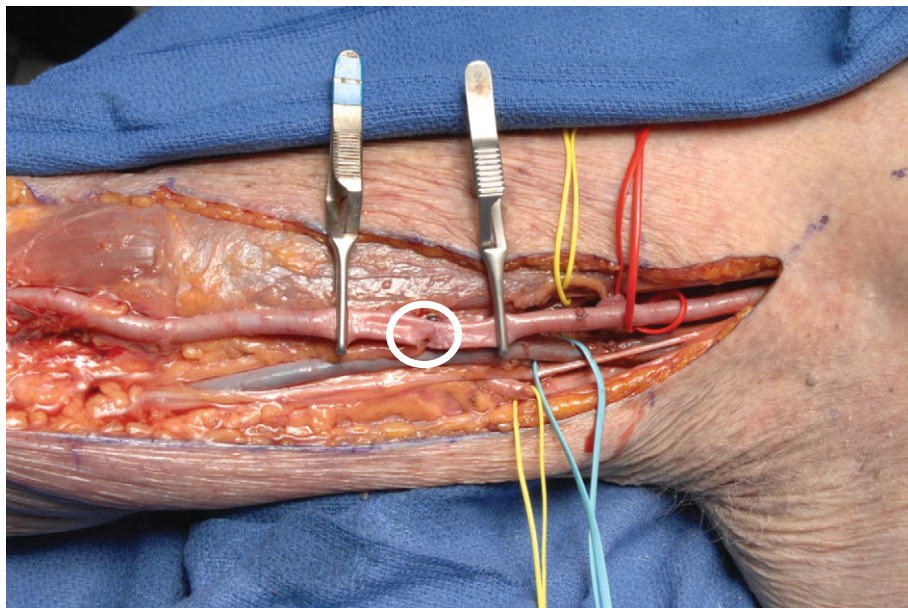


Figure 37.8 Proximal and distal control of the arterial injury (circle).

Vascular Repair

- Once the arterial injury is identified, proximal and distal control is obtained using vascular clamps (Figure 37.8).
- When definitive repair is feasible, debride the injured segment to expose healthy tissue. If a temporary shunt is utilized, debridement of the injured vessel is delayed until the time of definitive repair in order to preserve maximal length.
- A 3 F Fogarty catheter is passed proximally and distally to clear the vessel of thrombus (Figure 37.9a, b).

(a)

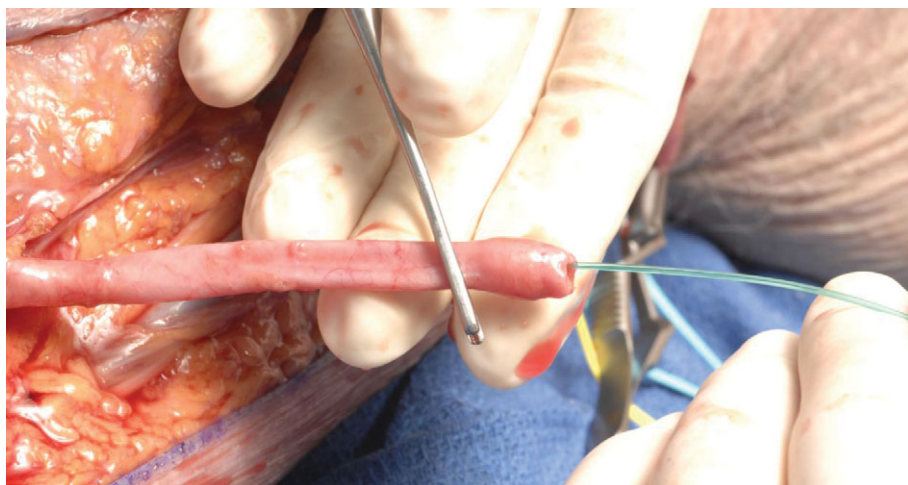
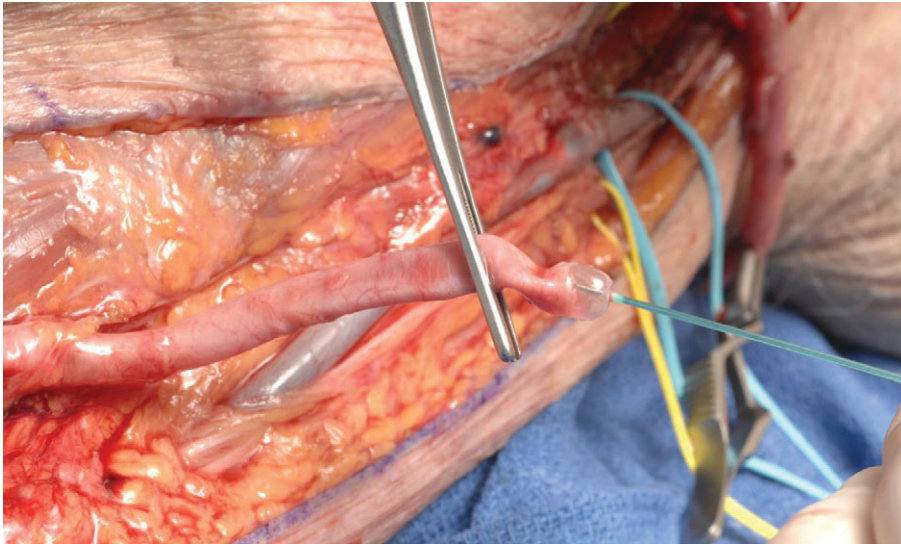


Figure 37.9 (a, b) Prior to shunt placement, repair, or graft, the artery is cleared of clot by proximal and distal passage of a 3 F Fogarty catheter.

(b)

**Figure 37.9** (cont.)

- Regional heparinization is achieved using heparinized saline solution as described above, followed by reapplication of the vessel clamps.
- Prior to definitive repair, the proximal and distal ends of the artery are trimmed to healthy vessel using Potts scissors. The ends can be beveled as needed for repair.
- Small caliber arteries and vein grafts can be dilated gently using a Fogarty catheter. Local anesthetic or papaverin solution can be used regionally to counteract vasospasm.
- Repair is achieved by primary repair or by utilizing a reverse autologous vein graft as the conduit. A PTFE interposition graft remains the last resort.
- The vascular anastomosis is performed using a running or interrupted monofilament suture, with the needle passing from the intima to adventitia on the artery side in order to minimize the risk of intimal flaps and dissection. The more technically complex anastomosis is created first, and the

artery is vented to release air bubbles prior to securing the final suture line.

- After restoration of blood flow, distal pulses should be documented and the surgeon should consider an on-table angiogram prior to leaving the operating room, if there is any question regarding flow.

Temporary Shunt

- When a temporary shunt is utilized as part of damage control, an O silk tie is used to secure the shunt proximally and distally (Figure 37.10a). An additional tie is placed around the middle of the shunt. The ties are then secured together around the center of the shunt to prevent migration of the shunt during patient transfer (Figure 37.10b).
- The presence of distal flow must be confirmed after shunt placement prior to leaving the operating room.

(a)

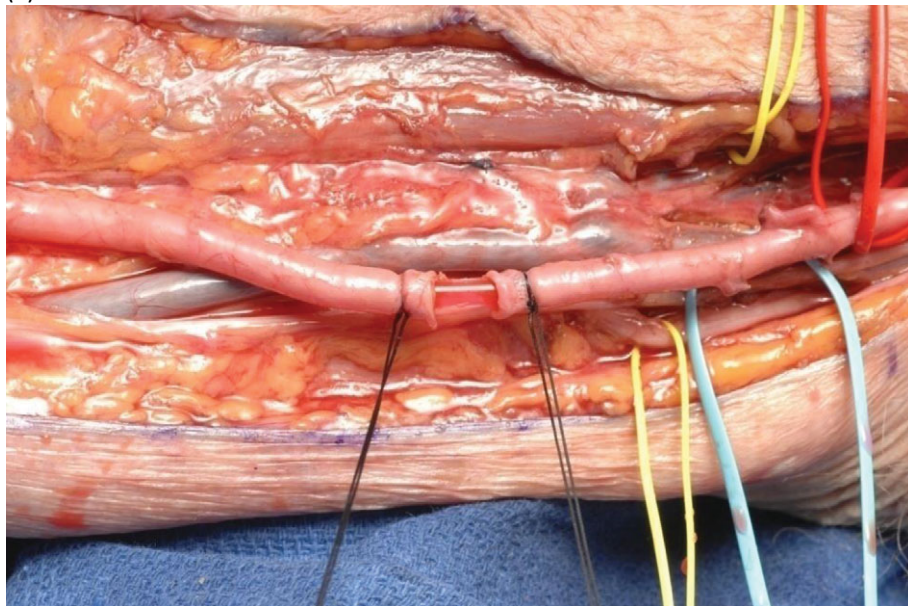
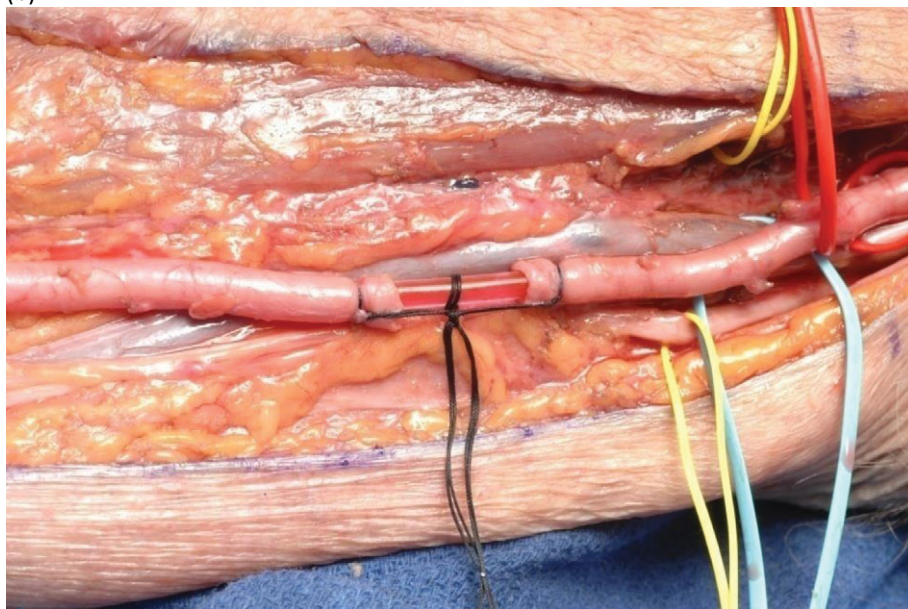


Figure 37.10 (a) A temporary shunt is placed in the injured vessel and an O silk tie is used to secure the shunt proximally and distally. (b) An additional tie is placed around the middle of the shunt. The ties are finally tied together around the center of the shunt to prevent dislodgement during patient transfer.

(b)



Tips and Pitfalls

- The median and ulnar nerves are in close proximity to the brachial artery and it is important to prevent iatrogenic nerve injury. High-risk areas for injury include ulnar nerve injury with initial exposure prior to posterior retraction of the nerve with the triceps brachii and injury to the median nerve as it crosses anteriorly over the brachial artery.
- During proximal brachial artery dissection, whenever possible, preserve the profunda brachial artery, as it provides significant collateral circulation to the lower arm.
- A single surgeon should perform the Fogarty catheter passage. The resistance placed on the balloon during thrombus extraction is a dynamic process, and care must be taken not to exert excessive force on the intima and create iatrogenic injury.
- After thrombus extraction, there should be generous forward and backflow. If there is not adequate flow prior to creation of the anastomosis, consider distal clot or a missed injury.
- In the event of a destructive injury, it is important to adequately prepare the anastomotic bed by debriding all

devitalized tissue. Failure to do so can interfere with graft and wound healing and lead to secondary infection, graft failure, or anastomotic complications.

- When sizing the length of the saphenous vein graft, it is important to place the arm in gentle flexion of 10°–20°. A common mistake is redundant graft length, which will lead to kinking of the graft.
- Arterial repair or anastomosis must be performed without tension. In select cases, such as in knife wounds, gentle mobilization of the proximal and distal ends of the artery can allow primary anastomosis. In most cases with gunshot wounds or blunt trauma, a reverse interposition vein graft is required.
- During shunt placement at the initial surgery, avoid debridement of the injured vessel. The final debridement should be performed beyond the shunt, anchoring ties at the time of definitive reconstruction.
- Compartment syndrome of the forearm is a common complication after brachial artery injury, especially with associated extensive soft tissue trauma or prolonged ischemia. Evaluate intraoperatively and postoperatively for clinical signs of compartment syndrome, including direct measurements of compartment pressures, when appropriate. Postoperatively, routine monitoring of CPK levels is important. Consider early fasciotomy in appropriate cases.

Upper Extremity Fasciotomies

Demetrios Demetriades

Surgical Anatomy

- The arm is divided into two muscle compartments:
 - The anterior compartment, which contains the biceps, the brachialis, and coracobrachialis, all innervated by the musculocutaneous nerve.
 - The posterior compartment, which contains the triceps, which is innervated by the radial nerve.
- The forearm is divided into three muscle compartments:
 - The anterior or flexor compartment, which contains the muscles responsible for wrist flexion and pronation of the forearm. These muscles are innervated by the median and ulnar nerves and receive blood supply mainly from the ulnar artery.
 - The posterior or extensor compartment, which contains the muscles responsible for wrist extension. They are innervated by the radial nerve and the blood supply is provided mainly by the radial artery.
 - The mobile wad is a group of three muscles on the radial aspect of the forearm that act as flexors at the elbow joint. These muscles are often grouped together with the dorsal compartment. The blood supply is provided by the radial artery and the innervation by branches of the radial nerve.
- The hand includes ten separate osteofascial compartments:

The transverse carpal ligament, over the carpal tunnel, is a strong and broad ligament. The tunnel contains the median nerve and the finger flexor tendons.

General Principles

- Common causes of upper extremity compartment syndrome include vascular injuries, severe fractures, crush injuries, extrinsic compression devices such as casts and dressings, extravasation of intravenous infusions, burns, edema from infection, and snakebites. This complication can also occur in unconscious or obtunded patients due to severe drug or alcohol intoxication and prolonged limb compression, injection of illicit drugs, and spontaneous bleeding in a muscle compartment due to pharmacological anticoagulation or bleeding disorders.

- The diagnosis of compartment syndrome is made by a combination of clinical and lab findings and, in some cases, with measurement of compartment pressures. The most common clinical signs and findings include a tense compartment and severe pain, usually out of proportion. Characteristically, the pain becomes worse with passive stretching of the elbow, the wrist, or the fingers, depending on the site of the compartment syndrome. However, it might be difficult to elicit pain in unconscious or pharmacologically sedated patients. Other signs, such as paresthesia, pallor, pulselessness, or paralysis, may be present, and they are usually late signs. When in doubt, the compartment pressures should be measured.
- The compartment syndrome is a potentially limb- and life-threatening condition. Renal failure due to myoglobinemia and myoglobinuria is a serious systemic complication due to delayed diagnosis and treatment. Volkmann's ischemic contracture is another complication resulting in permanent disability. In extreme cases, it may cause muscle necrosis and limb loss.



Figure 38.1 Advanced compartment syndrome of the left hand. Note the severe edema and the color changes of the skin.

(a)



(b)



Figure 38.2 Delayed treatment of upper extremity compartment syndrome with muscle necrosis (a), requiring extensive muscle debridement (b).

- Familiarity with the technique of muscle compartment pressure measurement is essential for all physicians taking care of trauma patients.
- The normal muscle compartment pressure is <10 mmHg. Acute increase of the pressure to >30 mmHg may result in compartment syndrome, with muscle and nerve ischemia.
- An absolute muscle compartment pressure of >30 or 40 mmHg is considered by many surgeons as a surgical emergency. An alternative to the absolute compartment pressure is the compartment perfusion pressure (CPP), as calculated by: $CPP = \text{Diastolic Pressure} - \text{Compartment Pressure}$. A CPP <30 mmHg is a surgical emergency and an indication for fasciotomy.
- Reversible muscular ischemia and neuropraxia occur up to 4–6 hours of ischemia. Irreversible muscular ischemia and axonotmesis occur beyond 6 hours of ischemia.
- The prognosis of acute compartment syndrome depends on the extent and duration of the pressure maintained in the compartment. Failure to decompress a compartment syndrome will result in progressive muscle and nerve ischemia, leading to permanent nerve damage, muscle necrosis, and myoglobinemia with kidney damage.
- The most common muscle compartment in the upper extremity affected by compartment syndrome is the

anterior (flexor) compartment of the forearm. The upper arm is the least commonly affected.

Special Surgical Instruments

- Stryker intra-compartmental pressure measuring system, using an 18 gauge side-ported needle, should be available for measuring compartment pressures, if needed (see technique in [Chapter 44](#) Lower Extremity Fasciotomies)
- For vessel-loop shoelace wound closure: vessel loops and skin staples
- Negative pressure dressing system (NPDS)

Positioning

The affected arm is placed 45° from the body on an arm board. The chest, arm, forearm, and hand are prepped into the surgical field.

Upper Arm Fasciotomy

- The two upper arm muscle compartments can be released through a single lateral skin incision, extending from the deltoid insertion to the lateral epicondyle.

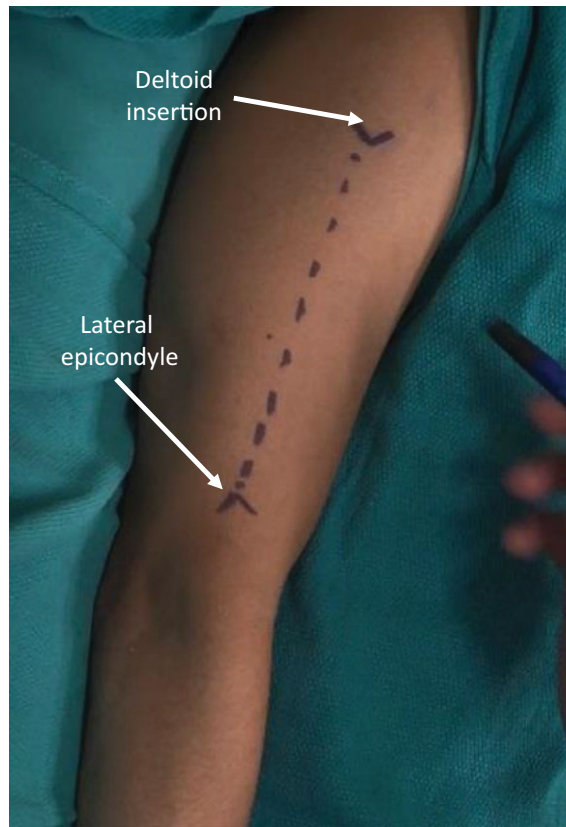
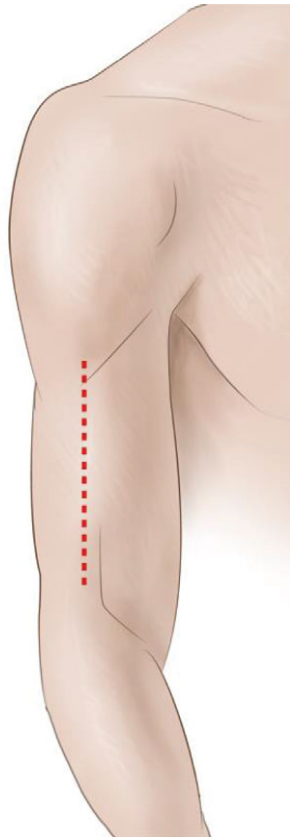


Figure 38.3 (a, b) Right upper arm fasciotomy. The two muscle compartments can be released through a single lateral skin incision from the deltoid insertion to the lateral epicondyle.

- At the fascial level, two skin flaps are mobilized anteriorly and posteriorly.
- The intermuscular septum between the anterior and posterior compartment is identified and the fascia over each compartment is incised longitudinally.

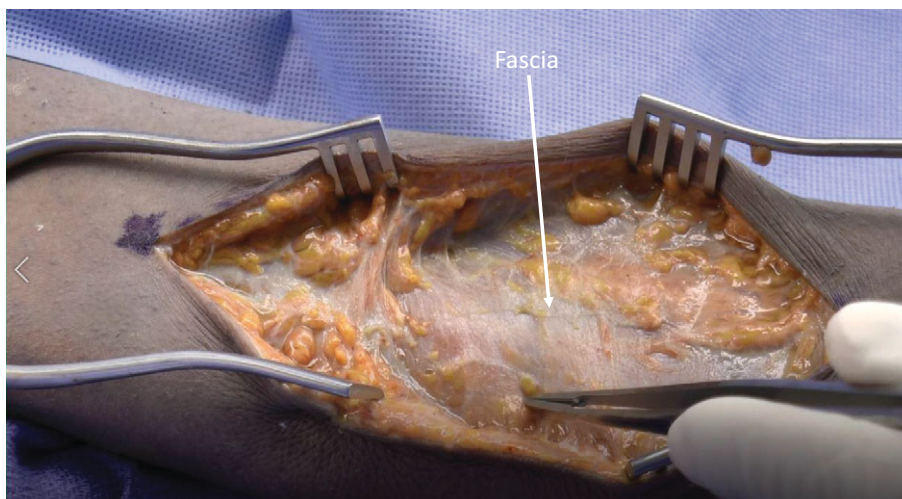


Figure 38.4 Right upper arm fasciotomy. The skin and subcutaneous tissue are dissected down to the fascia and skin flaps are mobilized anteriorly and posteriorly.

(a)

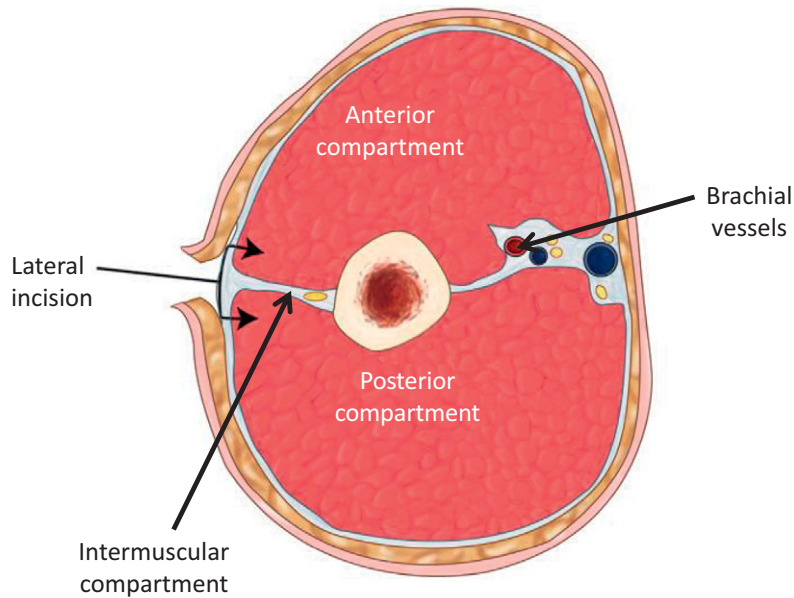
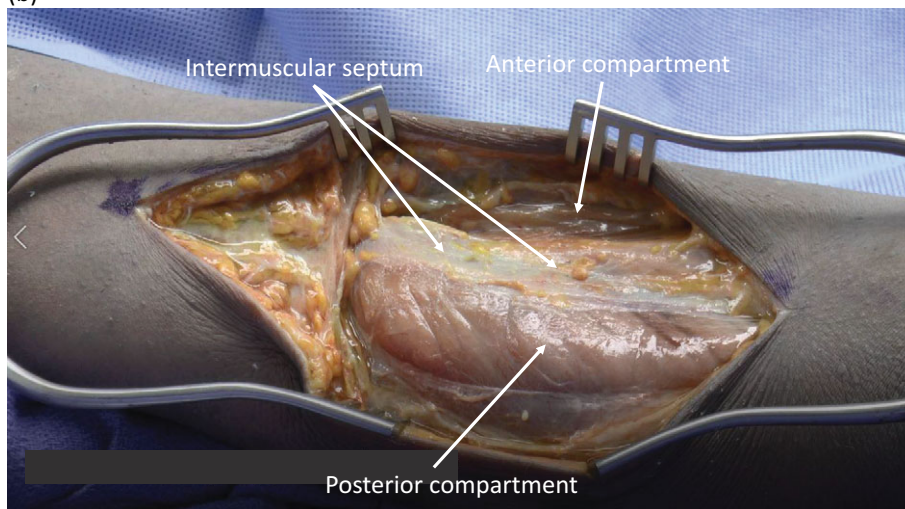


Figure 38.5 (a) Decompression of the two upper arm compartments of the right arm, through a lateral incision. The intermuscular septum between the anterior and posterior compartments is identified and the fascia over each compartment is incised longitudinally. (b) Decompression of the two upper arm compartments of the right arm through a lateral incision: the fascia over the anterior and posterior compartments is incised longitudinally and the muscle compartments are exposed. Note the intermuscular septum which separates the two groups of muscles.

(b)



Forearm and Hand Fasciotomies

Incisions

- Various incisions have been described to decompress the three compartments of the forearm. The most common approach utilizes two incisions (a dorsal and a volar incision) to decompress the three compartments.
- The most commonly described volar or anterior incision is the so called "Lazy S." The incision begins just proximal to the antecubital fossa, in the groove between the biceps and triceps. It is extended in a curvilinear fashion toward the radial aspect of the mid forearm and then curved back towards the ulnar aspect of the forearm at the wrist. The incision is then carried transversely to the center of the wrist and then carried onto the hand curving up onto the thenar eminence.

(a)

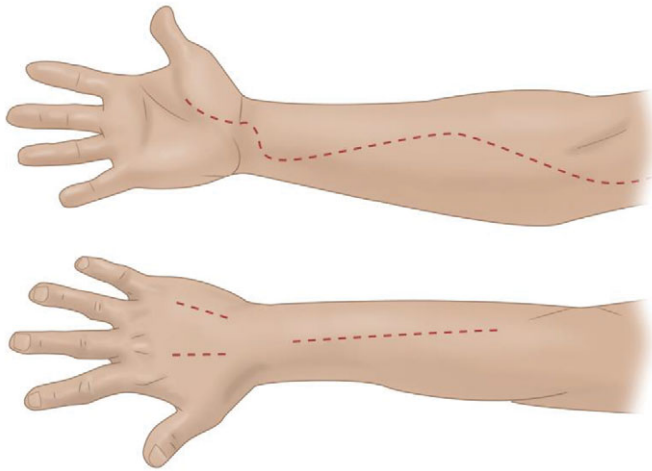


Figure 38.6 (a) The standard volar and dorsal incisions used to perform fasciotomy of the forearm and the hand. (b) The incision for decompression of the volar (anterior) and mobile wad compartments demonstrated on the right forearm.

(b)



- The skin and subcutaneous tissues of the forearm are dissected down to fascia and skin flaps are raised on both sides of the incision. The fascia over the flexor muscles is

incised with longitudinal slits and the bellies are exposed. It is important that ALL muscle groups are decompressed!

(a)

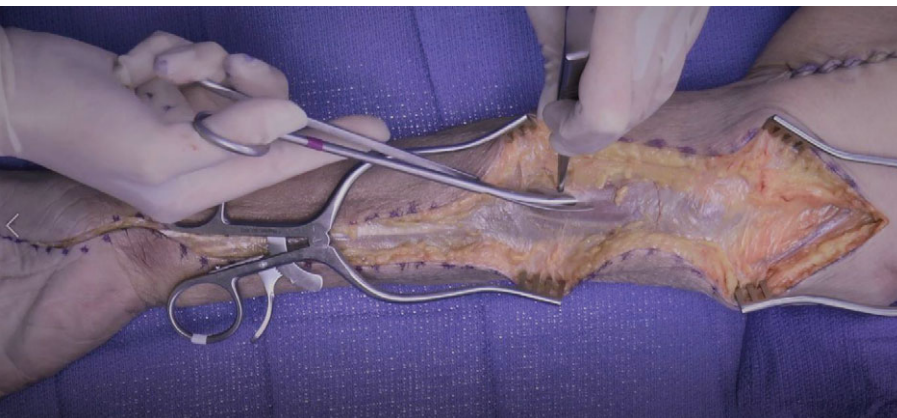


Figure 38.7 (a, b) Left forearm fasciotomy. Scissors are used to open the sheath (epimysiotomy) overlying the muscle bellies of the volar (anterior) and mobile wad compartments. All muscle groups should be opened.

(b)

**Figure 38.7** (cont.)

- At the wrist, the carpal tunnel is decompressed with complete division of the transverse carpal ligament, taking

care to prevent injury to the median nerve which is located just under the ligament.

(a)

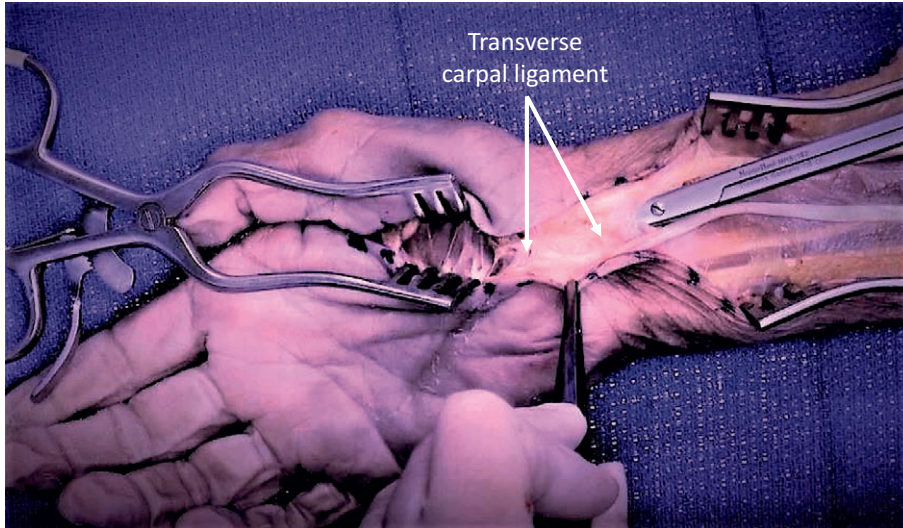
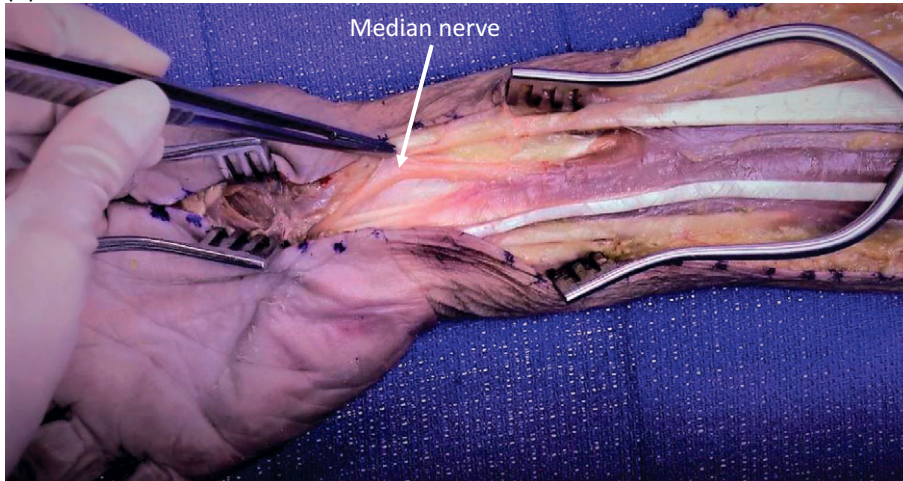


Figure 38.8 (a) The transverse carpal ligament over the carpal tunnel is a strong and broad ligament and should be divided for adequate decompression. (b) Exposed median nerve after division of the transverse carpal ligament (right wrist).

(b)



- Adequate decompression of the volar forearm and palmar hand requires wide epimysiotomy (division of the muscle sheath) over all muscle bellies of the volar forearm, as well as carrying the incision onto the thenar aspect of the palm to completely decompress the flexor retinaculum.
- The posterior (dorsal) compartment is opened with a longitudinal dorsal incision extending from the elbow to the wrist (see [Figure 38.4a](#)), coursing between the mobile extensor wad and extensor digitorum muscle bellies. All the muscles should be decompressed with longitudinal slits of the overlying fascia.

(a)



Figure 38.9 (a) Decompression of the dorsal compartment of the right forearm. The fascia over each of the muscle bellies is opened. (b) Left forearm fasciotomy of the extensor (dorsal) compartment and dorsum of the hand, with excision of dead muscles (circle).

(b)



- The hand's osteofascial compartments can be released with carpal tunnel release and two dorsal incisions. For complete hand fasciotomies, in addition to the division of the transverse ligament over the carpal tunnel, as described above, two incisions are made on the

dorsum of the hand over the second and fourth metacarpal spaces. The extensor tendons are retracted, and the underlying compartments are opened with longitudinal slits on the fascia, on either side of each tendon.

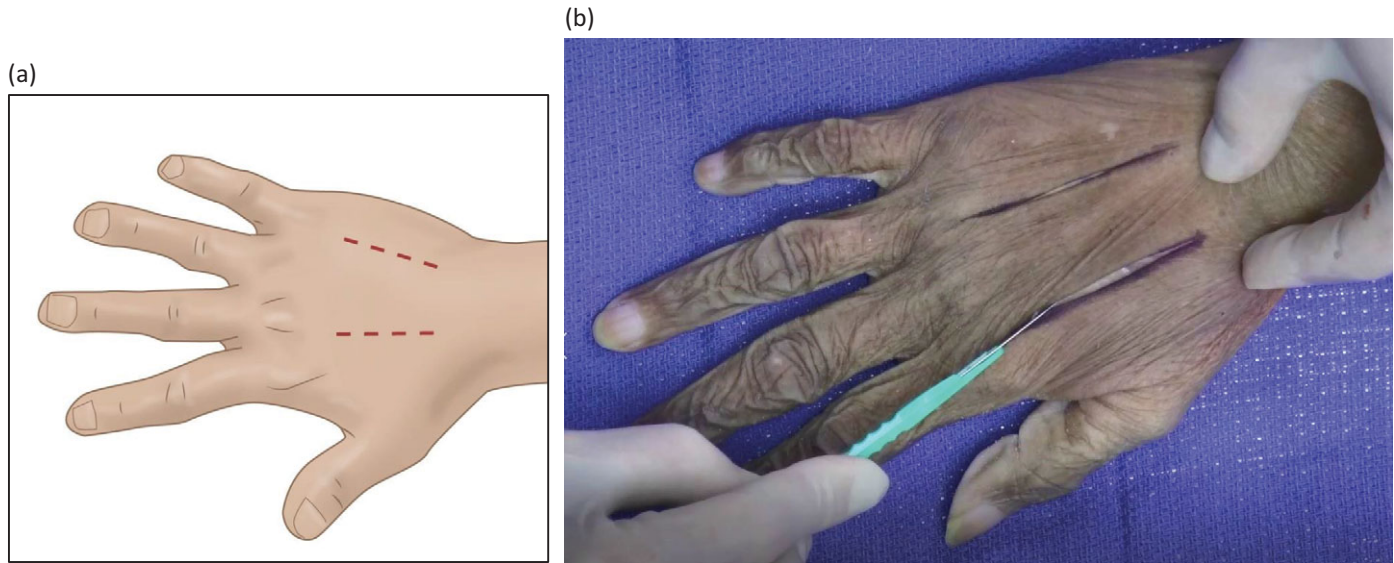


Figure 38.10 (a, b) The interosseous compartments of the hand are decompressed via two incisions placed on the dorsum over the second and fourth metacarpal spaces.

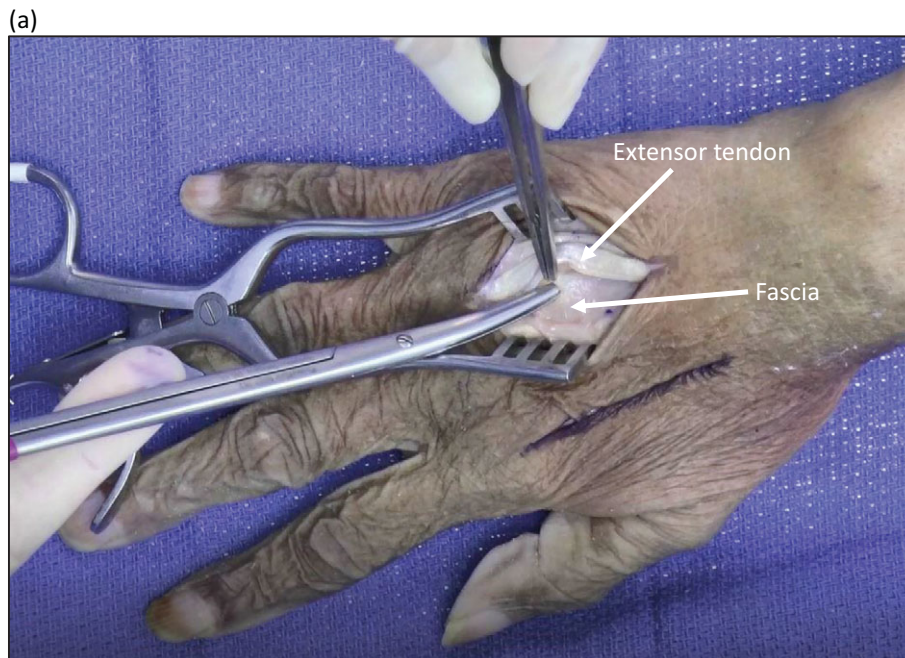
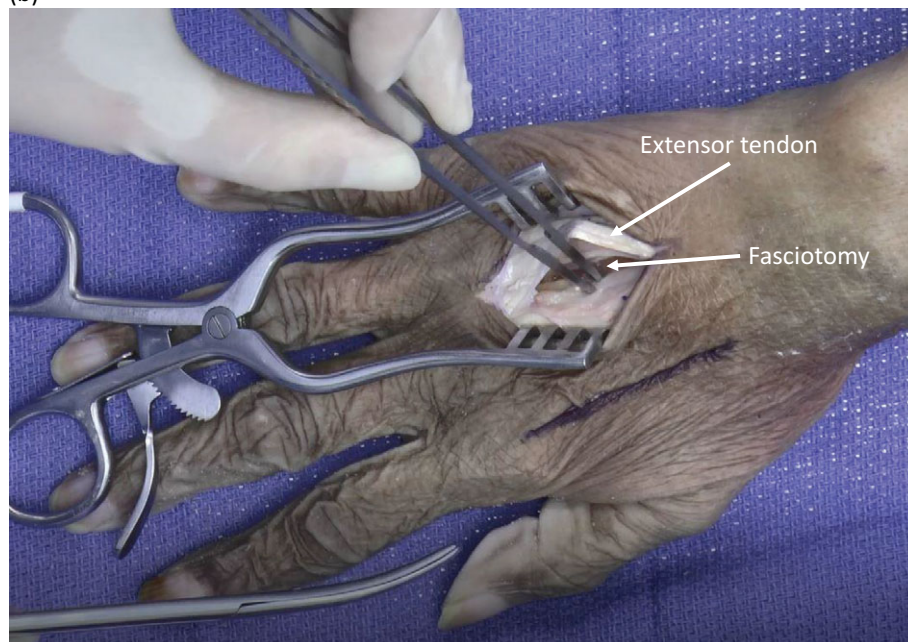


Figure 38.11 (a) Dorsal fasciotomy of the right hand. The extensor tendon is retracted to expose the fascia over the interosseous compartments. **(b)** The extensor tendons are retracted, and the fascia is divided and the underlying compartments are opened with longitudinal slits on either side of each tendon. **(c)** Completed fasciotomy after longitudinal slit of the fascia over the interosseous compartments on either side of the tendon.

(b)



(c)



Figure 38.11 (cont.)

Fasciotomy Wound Management

- The skin should initially be left open and a moist dressing should be placed on the muscle bellies to prevent desiccation.
- Negative pressure therapy dressing (VAC) is a useful modality to manage the fasciotomy sites. It prevents wound

retraction, removes excessive soft tissue edema, and facilitates delayed primary skin closure. However, its application in the presence of incomplete hemostasis may result in increased bleeding. It is advisable that this dressing is used after the second relook operation, when hemostasis is complete.



Figure 38.12 Negative pressure dressing system over a forearm fasciotomy.

- Vessel-loop shoelace wound closure is a useful technique to achieve delayed primary skin closure (see [Chapter 44](#) Lower Extremity Fasciotomies)
- Delayed split-thickness skin grafting may be necessary for wound closure, if primary skin closure is not possible.

Tips and Pitfalls

- Delayed diagnosis is a common error! High index of suspicion, serial clinical examinations, compartment pressure measurements, and serial CPK levels remain the cornerstone of early diagnosis.
- Elevated CPK levels in an unconscious patient should alert to the possibility of muscle compartment syndrome!
- In suspected compartment syndrome, the pressures should be measured in all muscle compartments. The pressures may be normal in one compartment and abnormal in the adjacent one.
- Poor knowledge of the anatomy of the extremity muscle compartments is the most common cause of delayed



Figure 38.13 Coverage of arm and forearm fasciotomy with split-thickness skin graft.

diagnosis, incomplete fasciotomy or iatrogenic damage to the neurovascular bundle.

- The transverse carpal ligament is broader than most surgeons realize, and adequate decompression of the carpal tunnel requires full division of the ligament well up onto the thenar eminence of the hand.

Upper Extremity Amputations

Peep Talving and Jackson Lee

Surgical Anatomy

- The upper arm has two muscle compartments: the anterior, which includes the biceps, and the posterior, which includes the triceps muscle.
- The forearm has two major compartments: the anterior containing the flexor muscles, and the posterior containing the extensor muscles. The mobile wad creates the third compartment.
- The upper extremity is perfused by branches from the deep and superficial brachial artery. The proximal brachial artery lies in the groove between the biceps and triceps muscles. Distally, it courses in front of the humerus. At the antecubital fossa, it runs deep to the bicipital aponeurosis and bifurcates into the radial and ulnar arteries, just below the elbow. The artery is surrounded by the two concomitant brachial veins, which run on either side of the artery.
- The profunda brachial artery is a large branch arising from the proximal brachial artery distal to the teres major muscle and follows the radial nerve closely. It provides collateral circulation to the lower arm.
- The basilic vein courses in the subcutaneous tissue in the medial aspect of the lower arm. At the midpoint, it penetrates the fascia to join one of the brachial veins.
- The cephalic vein is entirely in the subcutaneous tissues, courses in the deltopectoral groove, and empties into the junction of the brachial and axillary veins.
- In the upper arm, the median nerve lies in front of the brachial artery. It then crosses over the artery midway down the upper arm, where distally it lies posteromedial to the artery.

- The ulnar nerve is behind the artery in the upper half of the arm. Midway down the arm, it pierces the intermuscular septum and courses more posteriorly, away from the artery, behind the medial epicondyle.

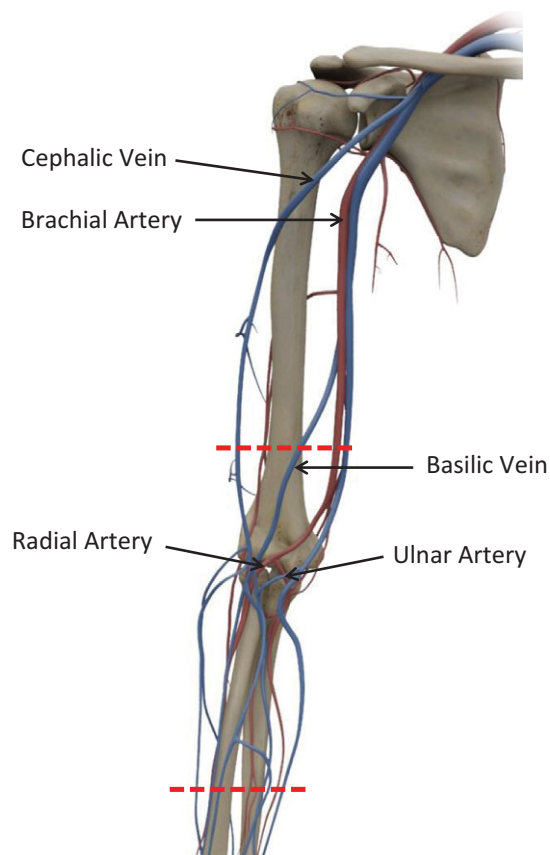


Figure 39.1 Anatomic illustration of the upper extremity with its typical arm and forearm amputation sites.

General Principles

- In many trauma cases with mangled extremity, primary amputation may be preferable to multiple and often futile, salvage attempts.
- The level and type of amputation should be determined by the general condition of the patient, the functional status of the limb, the type and severity of associated fractures, the extent of soft tissue damage, the adequacy of blood supply, and the availability of healthy skin flaps to cover the stump.
- Preserve as much functional length as possible to improve prosthesis fitting and functionality of the remaining limb.
- Use tourniquets to minimize blood loss. Elevation of the arm and the use of bandage or tourniquet exsanguinator should be considered. The inflation pressure is usually set at about 250 mmHg in adults or about 100 mmHg above the systolic pressure.
- All nonviable tissue must be removed.
- Nerves should be sharply divided as high as possible and allowed to retract. The ends of the nerves should be away from areas of pressure.
- Preserve sufficient soft tissues to cover the end of the bone without tension. However, avoid excessive amount of soft

tissues because it may interfere with the skin closure and prosthesis fitting.

- Bone edges should be filed to remove any sharp edges.
- Wounds should be closed without tension and suture lines should be placed away from weight bearing surfaces when possible.
- In the multiply injured patient in extremis, a guillotine amputation has been previously recommended. In contemporary settings, a skin-sparing damage-control amputation is the preferred intervention to preserve the soft tissues and skin for semi-elective completion when the condition of the patient stabilizes.

Special Instruments

- Use a wide arm table board to rest the injured extremity.
- Pneumatic tourniquet and bandage or tourniquet exsanguinator.
- Power saw or Gigli saw.
- Bone files or rasps and a periosteal elevator.
- Compression wraps for postoperative dressings are helpful to decrease edema and to shape the stump for early fittings of prosthetics.

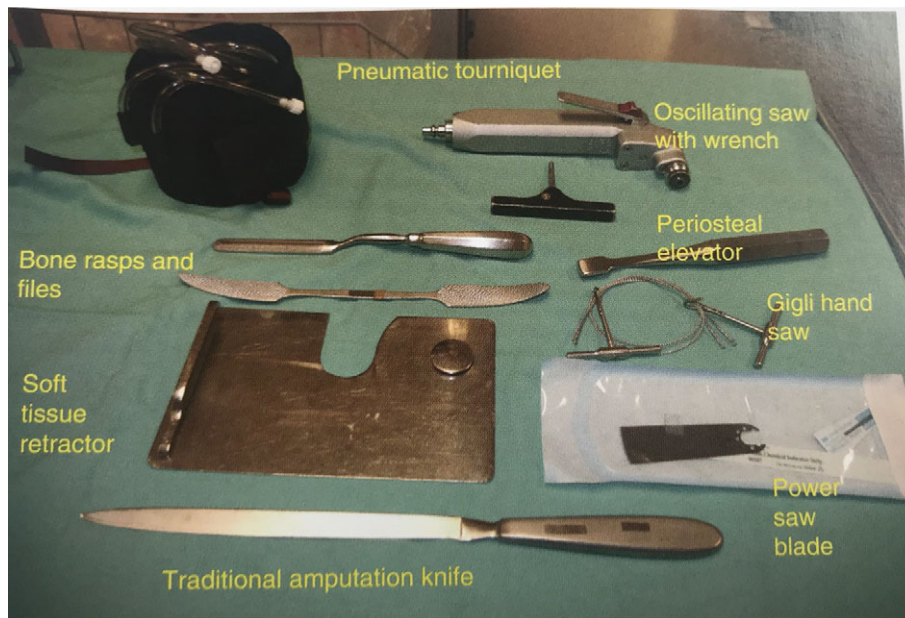


Figure 39.2 Essential instruments for amputations in trauma: pneumatic tourniquet, bandage, or tourniquet exsanguinators, power saw blade, bone files or rasps and a periosteal elevator.

Patient Positioning

- Supine position, with the injured arm abducted 90° on an arm table board.
- Skin preparation should include the hand and the whole arm circumferentially, up to the axilla and shoulder. The hand should be covered with a sterile stockinette. A Doppler probe should be in the sterile field to assess arterial supply.
- Apply a sterile pneumatic tourniquet if possible.

Above Elbow Amputation

Incision

- Perform a fish-mouth incision and create symmetrical anterior and posterior flaps. The medial and lateral apexes of the incision should be distal to the level of planned osteotomy (Figure 39.3).
- For amputations proximal to the middle of the humerus, preserve as much bone length as possible.
- For distal above-elbow amputation, preserve part of the humerus condyles to create a solid bone base for interaction with the prosthesis. If condyles cannot be spared, remove at least 4 cm of the distal humerus to facilitate prosthesis fitting with an elbow-lock mechanism, resulting in equal length of the contralateral arm.

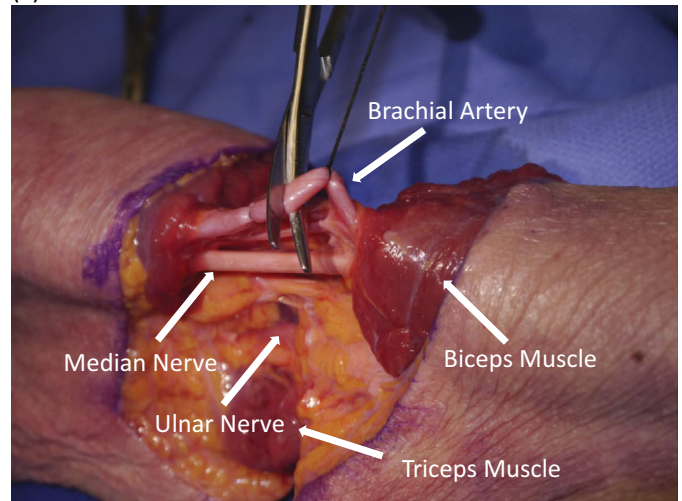
Procedure

- The skin incision should be carried through the subcutaneous tissue and fascia.
- The brachial artery should be identified in the groove between biceps and triceps muscles with the median nerve located medially. The brachial artery is identified, ligated, and divided (Figure 39.4a).



Figure 39.3 Left arm amputation fish-mouth incision with equal anterior and posterior musculocutaneous flaps.

(a)



(b)

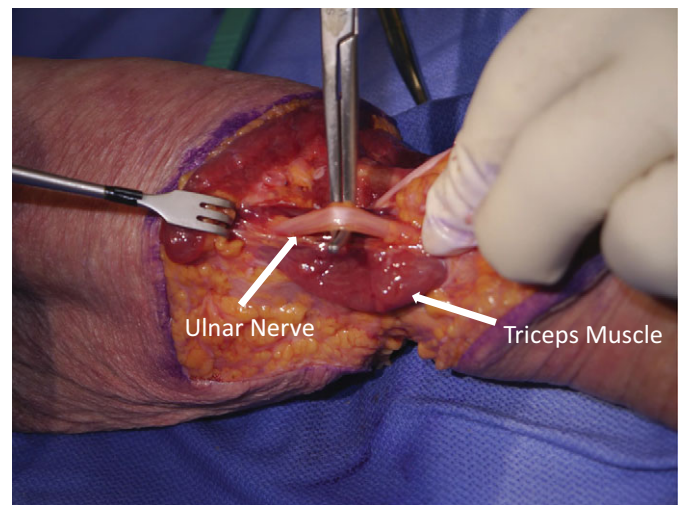


Figure 39.4 (a) Division of the left brachial artery. Note the close proximity of the median nerve. (b) The ulnar nerve is identified at the anteromedial aspect of the triceps muscle.

- The median nerve is retracted gently, distally, and sharply divided. This allows retraction of the nerve end into the soft tissues, away from the load-bearing surface.
- The ulnar nerve is located an inch posterior to the median nerve on the medial aspect of the triceps muscle. Likewise, the radial nerve is identified as it courses on the posterior aspect of the humerus deep to the triceps muscle. These nerves are divided, as described above (Figure 39.4b).
- The muscles are divided sharply to create the soft tissue flaps (Figure 39.5).
- The posterior (triceps) muscle flap is created longer to allow tension-free coverage of the bone upon closure (Figure 39.6).
- The periosteum is elevated proximal to the skin and muscle flap up to the point of planned bone division

(Figure 39.7a). The humerus is then divided with the power saw or Gigli saw (Figure 39.7b).

- The divided end of the humerus is smoothed with a rasp (Figure 39.7c).
- The triceps tendon is removed from the olecranon process and an adequate length of the triceps flap is fashioned for a myoplasty over the bone stump (Figure 39.8a, b).
- A drain is placed under the muscle flaps in appropriate cases.
- The posterior fascia of the triceps muscle is brought from posterior, over the bone, and secured to the anterior fascia of the biceps anteriorly (Figure 39.9).
- The skin is then closed over the fascia closure (Figure 39.10).

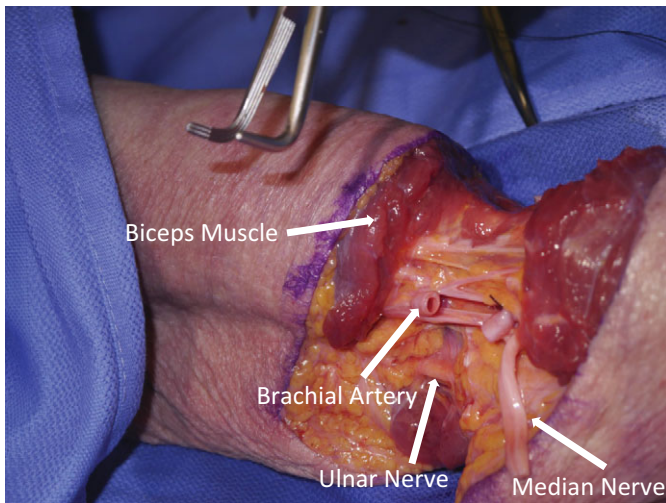


Figure 39.5 Photograph demonstrating divided biceps muscle, brachial artery, and the median nerve. The proximal median nerve has retracted under the divided biceps muscle.

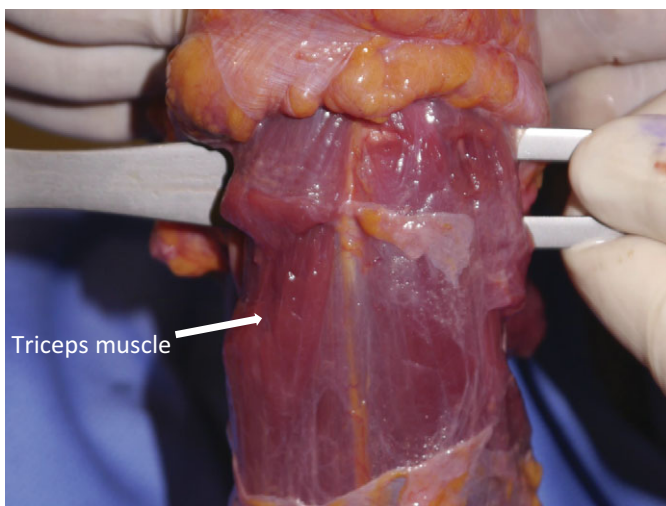


Figure 39.6 Division of the triceps muscle is easily performed over the hollow handle army-navy retractor. This approach facilitates a longer triceps flap for a tension free coverage over the osteotomy.

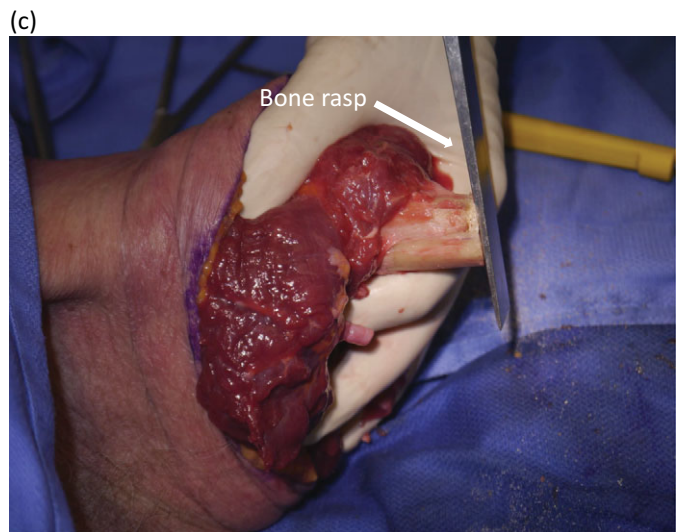
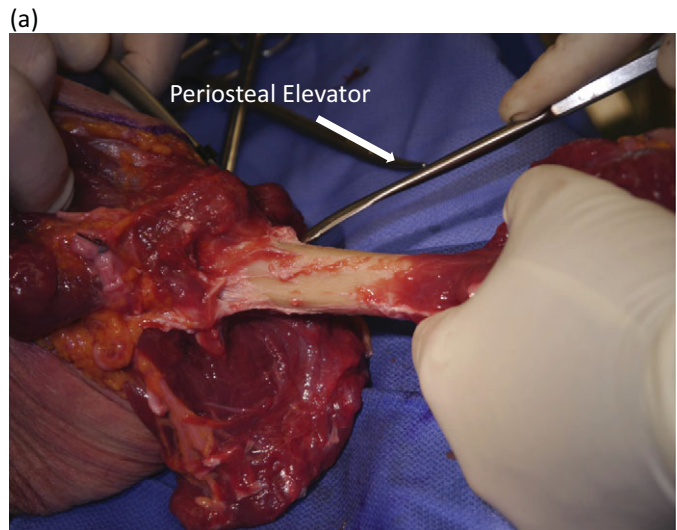


Figure 39.7 (a) The Cobb's periosteal elevator is used to clear the osteotomy site from the periosteum and soft tissues. (b) Division of the humerus with the Gigli saw. (c) Bone rasp is used to smoothen the edges of osteotomy.

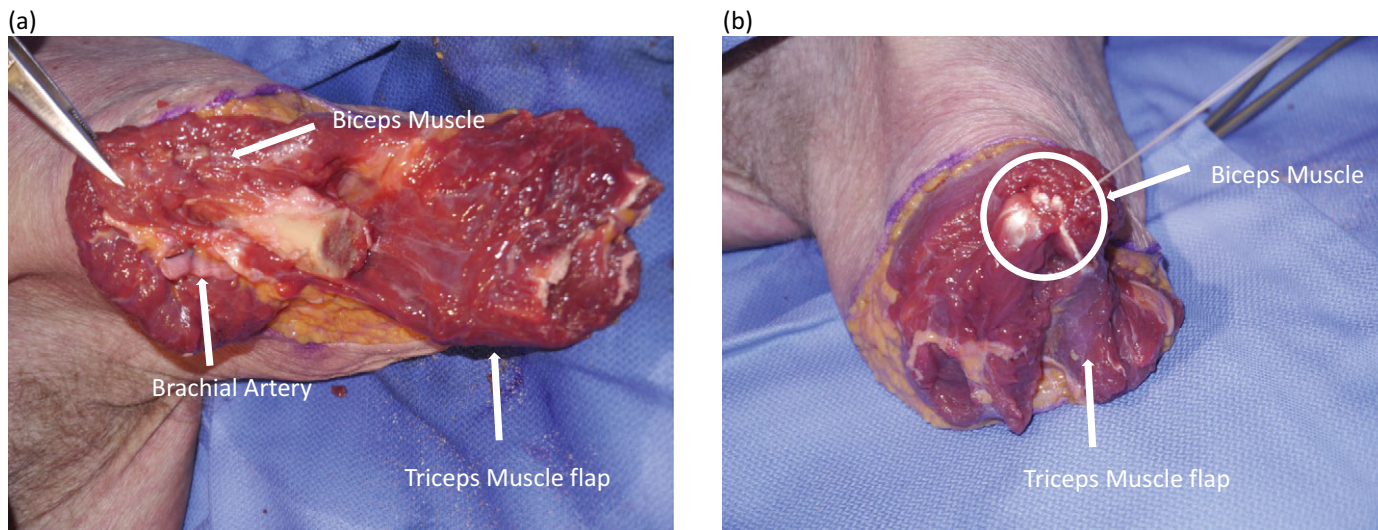


Figure 39.8 (a) The triceps flap is used to cover the bone stump. (b) Myoplasty (circle) using biceps and triceps flaps over the humerus stump.

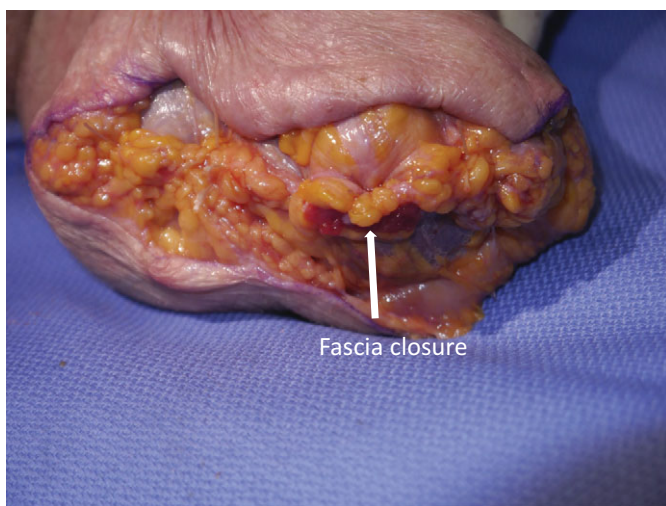


Figure 39.9 Closure of the fascia over the myoplasty suture line to cover the bone stump in a tension free fashion.

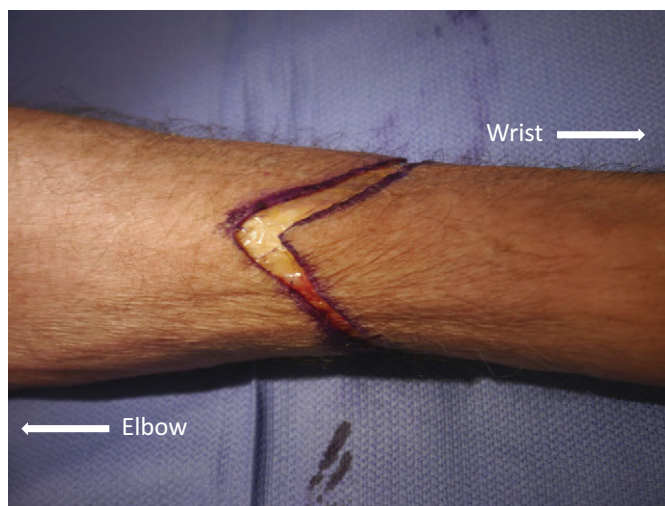


Figure 39.11 Photograph depicting left below elbow fish-mouth incision with equal anterior and posterior musculocutaneous flaps.



Figure 39.10 A tension-free skin closure completes the upper arm amputation.

Below Elbow Amputation

Incision

- Perform a fish-mouth incision, with symmetrical anterior and posterior flaps. The medial and lateral apexes of the incision should be distal to the level of planned bone division ([Figure 39.11](#)).

Procedure

- The skin incision is carried through the subcutaneous tissue and fascia.
- The radial and ulnar arteries should be identified laterally and medially, respectively, and ligated (Figure 39.12a–c).
- Similarly, the radial and ulnar nerves should be identified. Traction should be applied to the nerves prior to sharp division as described above.
- The muscles are then divided. Adequate soft tissue should be preserved to allow coverage of the bone. Avoid excess muscle bulk as it creates problems with skin coverage and the subsequent application of the prosthesis.
- The median nerve lies deep, on top of the interosseous membrane between the radius and ulna (Figure 39.12d). The nerve is sharply divided, as described above.
- The periosteum is elevated proximal to the skin and muscle flap, up to the point of planned bone division (Figure 39.13a). The radius and ulna are divided separately at the same length with the use of a power saw or Gigli saw (Figure 39.13b, c).
- Sharp ends of bone should be smoothed with a rasp.
- The anterior and posterior deep fascia are reapproximated and closed over the divided bones (Figure 39.14a, b).
- The skin is closed over the muscle (Figure 39.14c).

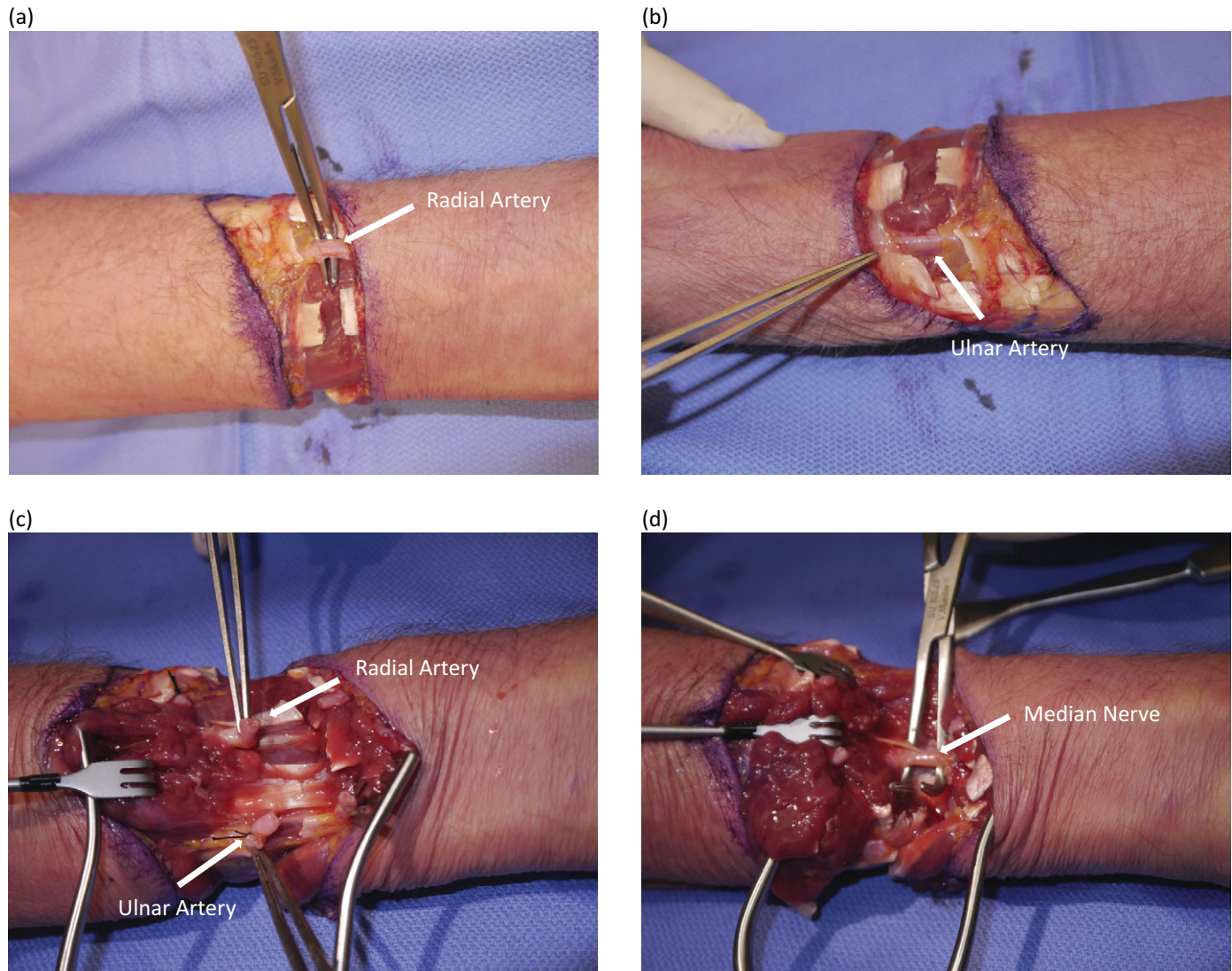


Figure 39.12 (a) The radial artery is identified under the brachioradial muscle and ligated. (b) The ulnar artery is identified between the flexor digitorum profundus and flexor carpi ulnaris muscles and ligated. (c) Photograph depicting volar aspect of the forearm amputation, with ligated radial and ulnar nerves. (d) Photograph showing the median nerve located on the interosseous membrane in a deep aspect of the forearm.

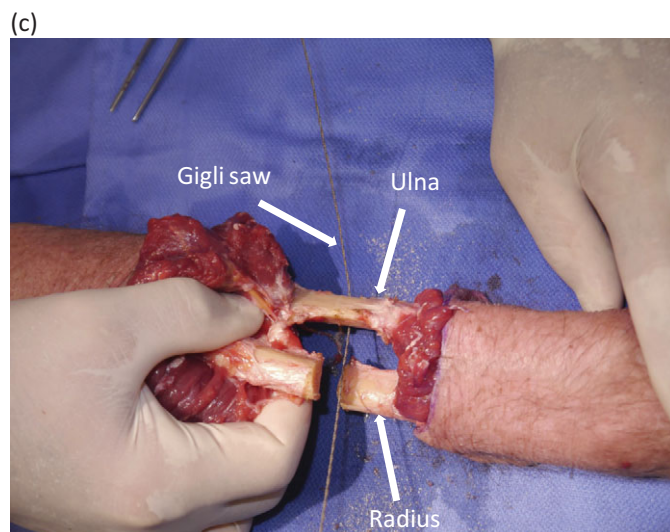
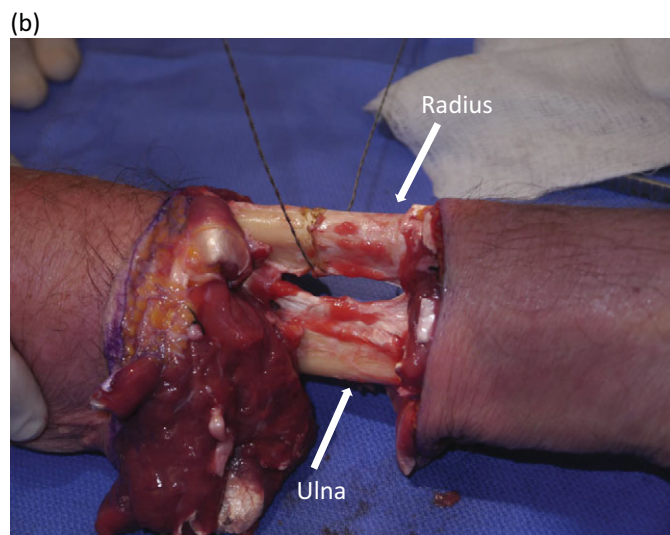
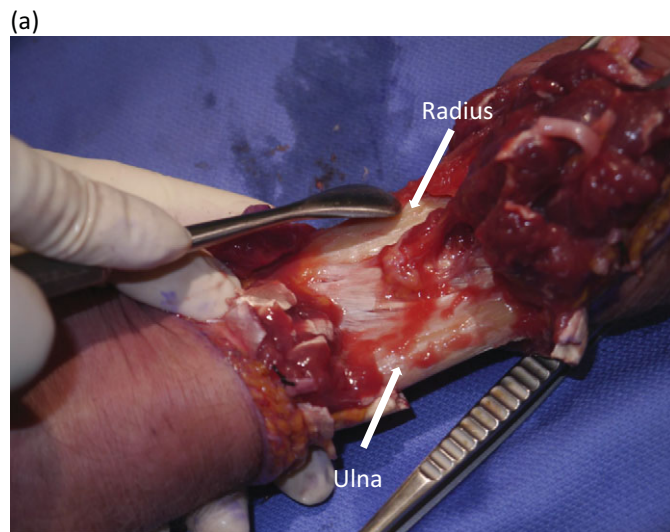


Figure 39.13 (a) Cobb's periosteal elevator is utilized to clear the radius and ulna from the periosteum and soft tissues. (b) Photograph demonstrating division of the radius with the Gigli saw. (c) Division of the ulna with the Gigli saw.



Figure 39.14 (a) Photograph showing equal musculocutaneous flaps for closure of the forearm amputation. (b) Fascia closure is achieved using absorbable sutures. (c) The stump is closed with nonabsorbable and tension-free suture line.

Tips and Pitfalls

- In many cases with a mangled extremity, primary amputation may be preferable to multiple and often futile salvage attempts.
- Skin-sparing damage-control amputation should be considered in patients in extremis.
- Preserve length to improve functional outcome, even if it requires a skin graft or other plastics procedures for coverage.
- There is no difference in neuroma formation whether or not the divided nerve is ligated. However, the transected nerve ends should be retracted and located in a well-cushioned tissue bed away from the load-bearing surface.

Femoral Artery Injuries

George C. Velmahos, Matthew J. Forestiere, and Rondi Gelbard

Surgical Anatomy

- The common femoral artery is a continuation of the external iliac artery and is approximately 4 cm long. It begins directly behind the inguinal ligament, midway between the anterior superior iliac spine and the symphysis pubis.
- The profunda femoris artery arises from the lateral aspect of the common femoral artery, towards the femur, approximately 3–4 cm below the inguinal ligament. The common femoral artery continues obliquely down the anteromedial aspect of the thigh as the superficial femoral artery.
- The superficial femoral artery exits the femoral triangle to enter the subsartorial canal and ends by passing through an opening in the adductor magnus to become the popliteal artery.
- In the upper third of the thigh, the femoral vessels are contained within the femoral triangle (*Scarpa's triangle*).
 - The femoral triangle is formed laterally by the medial border of the sartorius muscle, medially by the adductor longus, and superiorly by the inguinal ligament.
 - In the femoral triangle, the femoral vein lies medial to the femoral artery. The greater saphenous vein drains into the femoral vein about 3–4 cm below the inguinal ligament; further distally, the femoral vein lies posterior to the artery and maintains this relationship in the popliteal fossa. The femoral nerve and its branches are found lateral to the common femoral artery.
- In the middle third of the thigh, the femoral artery lies within the adductor canal (*Hunter's canal*), an aponeurotic tunnel in the middle third of the thigh that extends from the apex of the femoral triangle to the opening in the adductor magnus.
 - The adductor canal is bounded by the sartorius muscle anteriorly, the vastus medialis laterally, and the adductor longus and magnus posteromedially. A fascial plane between the vastus medialis and adductor longus and magnus covers the canal.
 - The canal contains the femoral artery and vein, the saphenous nerve which crosses from lateral to medial, and branches of the femoral nerve.

- The femoral vein courses from a medial position in the groin to a posterior and then lateral position with respect to the artery as it moves distally towards the knee.
- The greater saphenous vein courses medially to lie on the anterior surface of the thigh, before entering the fascia lata and joining the common femoral vein at the sapheno-femoral junction near the femoral triangle.

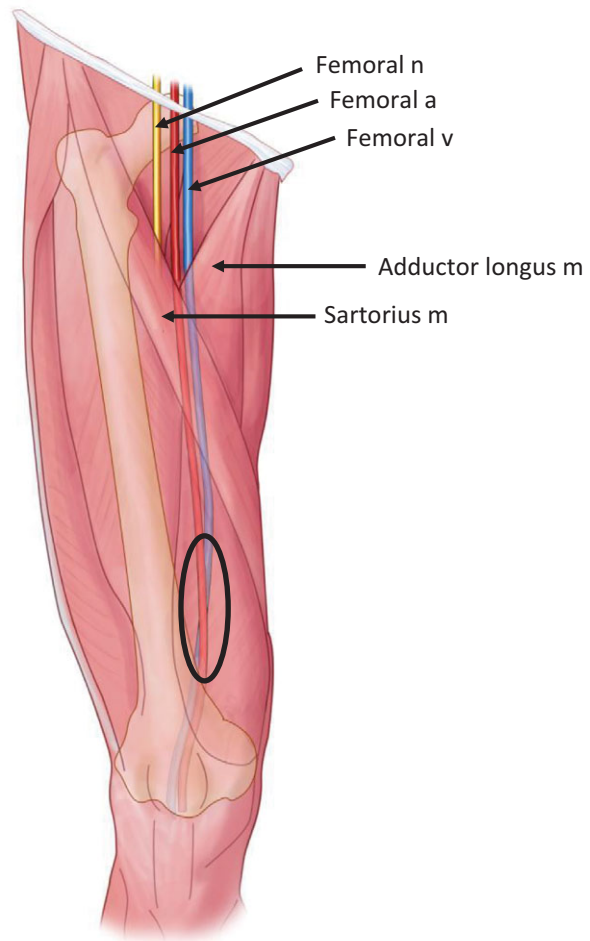


Figure 40.1 Anatomical relationship of the femoral artery and vein as they course down the anteromedial aspect of the thigh. Note the femoral vein coursing from a medial to a posterior and then lateral position with respect to the artery as it moves distally towards the knee (circle).

(a)

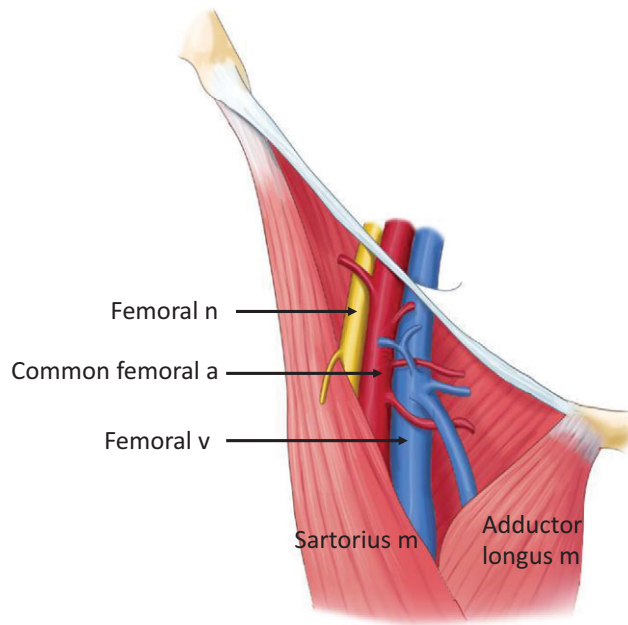
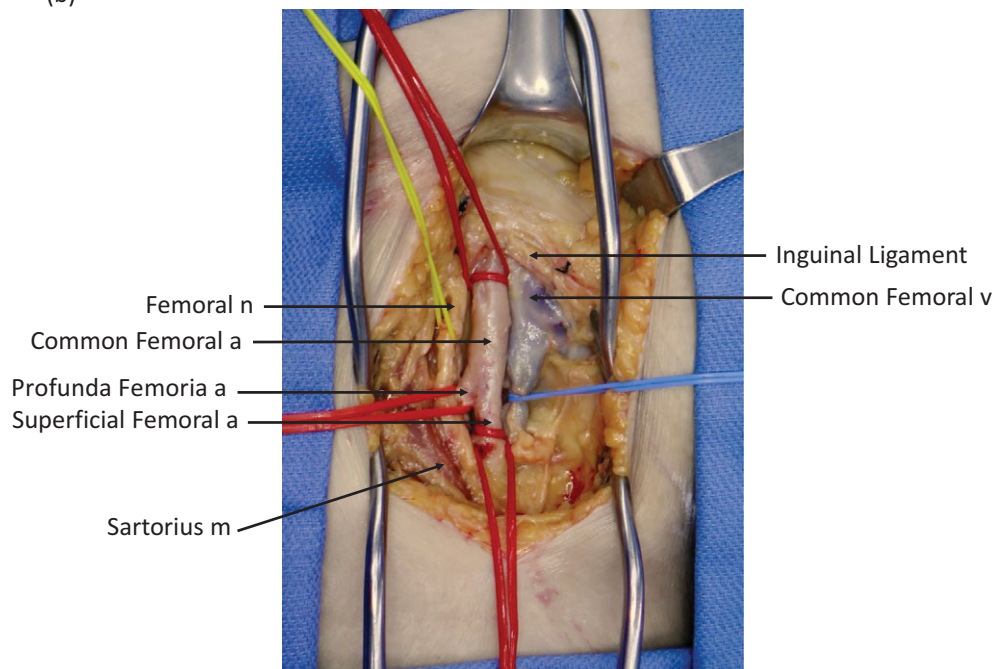


Figure 40.2 (a) Anatomy of the right femoral triangle. The vein lies medial to the femoral artery, while the femoral nerve and its branches are found lateral to the femoral artery. **(b)** Anatomy of the right femoral triangle as shown in this cadaveric dissection.

(b)



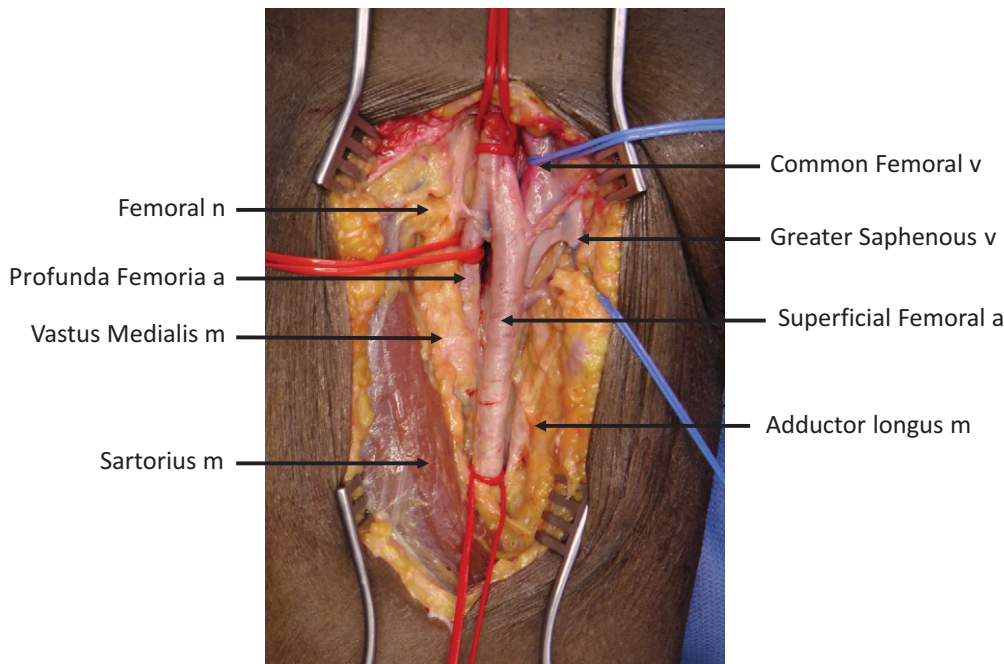


Figure 40.3 Right femoral triangle leading into adductor canal. Note the relationship of the femoral nerve lateral to the artery and the sapheno-femoral junction in relation to the profunda artery take-off. The superficial artery continues into the adductor canal, bound anteriorly by the sartorius muscle, vastus medialis muscle laterally, and adductor longus and magnus posteromedially.

General Principles

- The profunda femoris can be ligated without significant problems. However, ligation of the common or the superficial femoral artery results in ischemia and loss of limb in most patients. For patients requiring damage control, shunting is always preferable to ligation.
- Arterial reconstruction above the knee can safely be performed with a prosthetic or autologous graft. Injuries at the popliteal fossa should preferably be repaired with autologous vein.
- A Fogarty catheter should typically be passed proximally and distally to remove any clots. Systemic heparinization can be considered, but is not necessary if the patient is coagulopathic or has multisystem injuries at risk of bleeding. Local proximal and distal infusion of heparin solution (5,000 units in 100 mL of normal saline), however, is recommended for routine use.
- At the completion of the arterial repair, examine for a palpable peripheral pulse. On-table angiography should be considered in cases where only a Doppler signal is detected or any other abnormality is suspected at the vascular anastomotic lines.
- The extremity compartments should always be monitored perioperatively. Routine prophylactic fasciotomies are not indicated. However, therapeutic fasciotomies should be performed without delay.
- Continued postoperative monitoring with serial clinical examinations and serial serum creatine kinase (CK) levels should be performed.
- The femoral vein can be ligated in most cases without acute life- or limb-threatening consequences. In patients who are

hemodynamically stable, a venous repair can be considered if the complexity and duration of the procedure do not outweigh its expected benefits. Vascular shunting is also an option in isolated proximal venous injuries for damage control. Application of a compression bandage or elastic stocking may reduce the degree of postoperative edema.

Positioning

- The patient should be placed in the supine position, with the hip and knee slightly flexed and externally rotated. A bolster can be placed under the thigh and knee.

Incision(s)

A vertical incision is made approximately halfway between the pubic tubercle and anterior iliac spine directed towards the medial femoral condyle. The length of the incision is determined by the site of the vascular injury.

- For proximal common femoral vascular injuries, the incision may have to be extended proximally through the inguinal ligament to gain adequate proximal control at the external iliac artery level. It can also be curved superiorly and laterally, parallel to the inguinal ligament to allow retroperitoneal exposure of the iliac vessels.
- For injuries to the superficial femoral artery, a longitudinal incision is extended over the anterior border of the sartorius muscle. A useful external landmark is a line joining the middle of the inguinal ligament with the medial femoral condyle.
- Care must be taken to avoid injuring the greater saphenous vein in its superficial location in the subcutaneous tissues, along the medial edge of the incision.

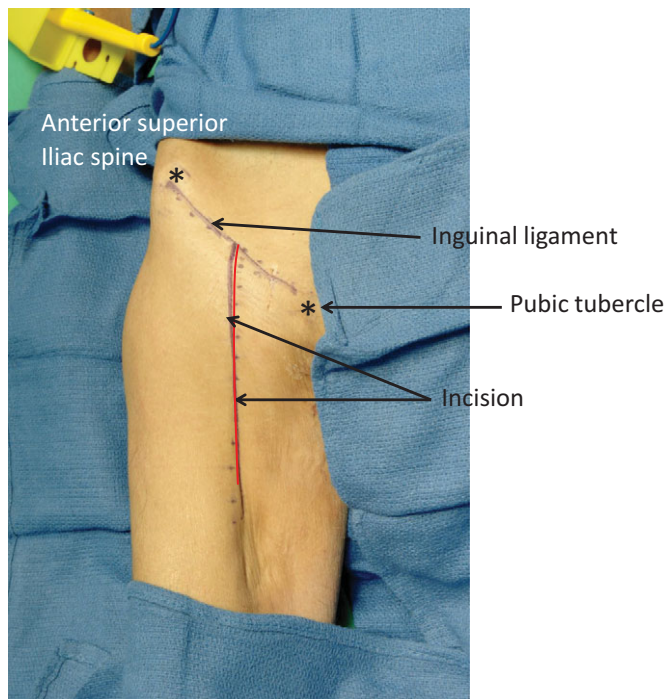


Figure 40.4 Incision for exposure of the femoral vessels. A vertical incision is made, starting approximately halfway between the pubic tubercle and anterior iliac spine, and with a direction towards the medial femoral condyle.

Exposure and Procedure

- Following the skin incision and dissection of the subcutaneous tissue and superficial and deep fascia, the femoral sheath is opened directly over the femoral artery, using a combination of cautery and sharp dissection. The femoral vein and the lymph nodes are medial to the artery. A self-retaining Weitlaner or cerebellar retractor is placed.
- The greater saphenous vein is identified along the medial edge of the incision and preserved, in case it is needed as an autologous graft.
- The common femoral artery is dissected circumferentially, and a vessel loop is placed around it for proximal control. The same approach is followed for the superficial femoral artery.
- The vessel loops around the common and superficial femoral arteries are retracted upwards and medially to expose the profunda femoris artery and a vessel loop is placed around it.

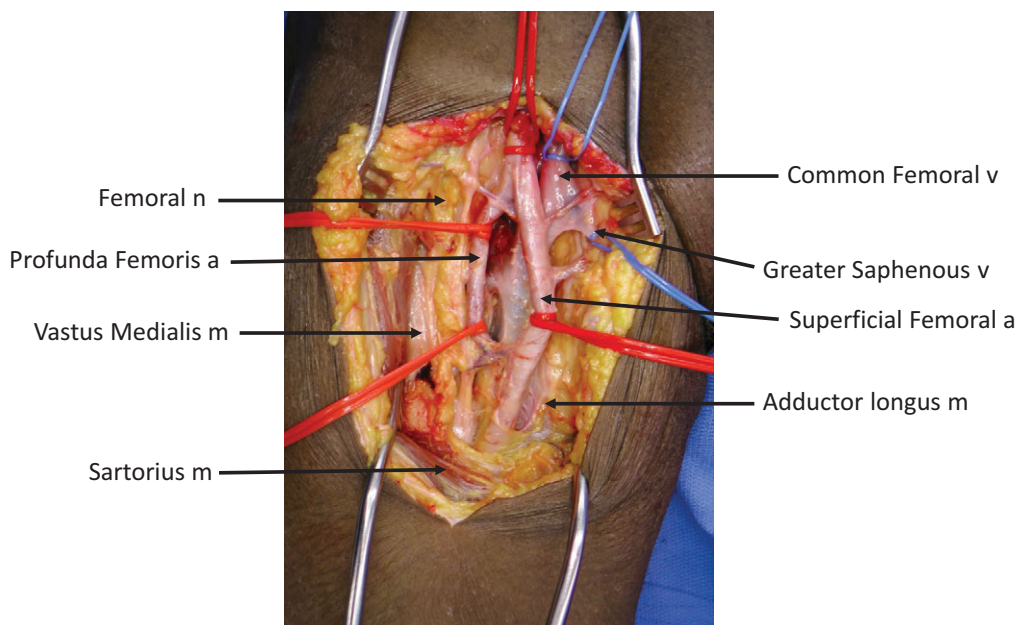


Figure 40.5 Exposure of the right femoral vessels: Medial and upward retraction of the superficial femoral artery show the profunda femoris artery and the femoral vein as they both course posterior to the superficial femoral artery as it enters the adductor canal.

- Exposure of the superficial femoral artery in the mid-thigh requires opening of the adductor canal by incising the aponeurosis, which forms its roof, retracting the sartorius and vastus medialis muscles laterally and the adductor longus medially.
- Distally, the superficial femoral artery is exposed by opening the aponeurotic roof of the adductor magnus canal. The very distal part of the artery exits from the adductor canal through the adductor magnus hiatus.
- In severely injured or unstable patients, or if the skillset of the surgeon precludes definitive repair, blood flow can be restored temporarily using a shunt. Injuries to the common femoral and superficial femoral arteries must eventually undergo definitive reconstruction.
- The femoral vein can be ligated without significant life- or limb-threatening problems. Repair should be considered only if it can be performed with simple techniques and without producing significant stenosis. Significant stenosis after repair can lead to an undesirable risk of deep vein thrombosis and pulmonary embolism, and in such cases a ligation may be a safer option.
- At the completion of operation, the muscle compartments of the lower leg should be evaluated and, in the appropriate cases, fasciotomies should be performed

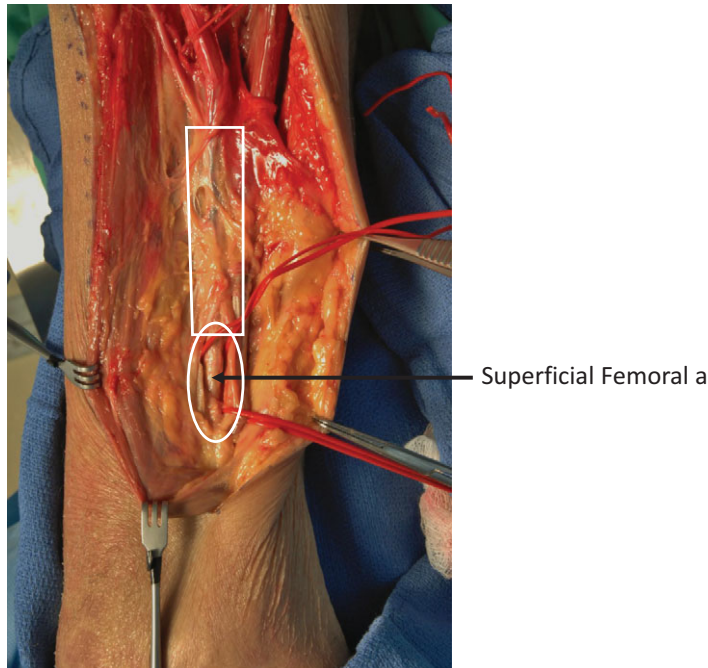


Figure 40.6 Exposure of the distal right superficial femoral artery requires opening of the aponeurotic roof of the adductor canal (white box). The artery exits from the adductor canal through the adductor magnus hiatus (white circle).

Tips and Pitfalls

- Patients with combined venous and arterial injuries are at particularly high risk of developing compartment syndrome.
- Although prophylactic fasciotomies are not recommended, the patient must be closely monitored postoperatively for the development of compartment syndrome.
- In hemodynamically stable patients, mannitol may be given intra- and postoperatively to decrease the risk of developing compartment syndrome.
- Because lymphatics are abundant in this area, lymph vessels should be ligated or controlled with small hemoclips if they are visualized to decrease formation of a lymphocele or lymph fistula, but not at the expense of time in a bleeding patient.
- Identification of the common and proximal superficial femoral artery may be difficult in cases with thrombosis and no pulse. Remember the external landmark, a line drawn from the middle of the inguinal ligament to the medial femoral condyle.

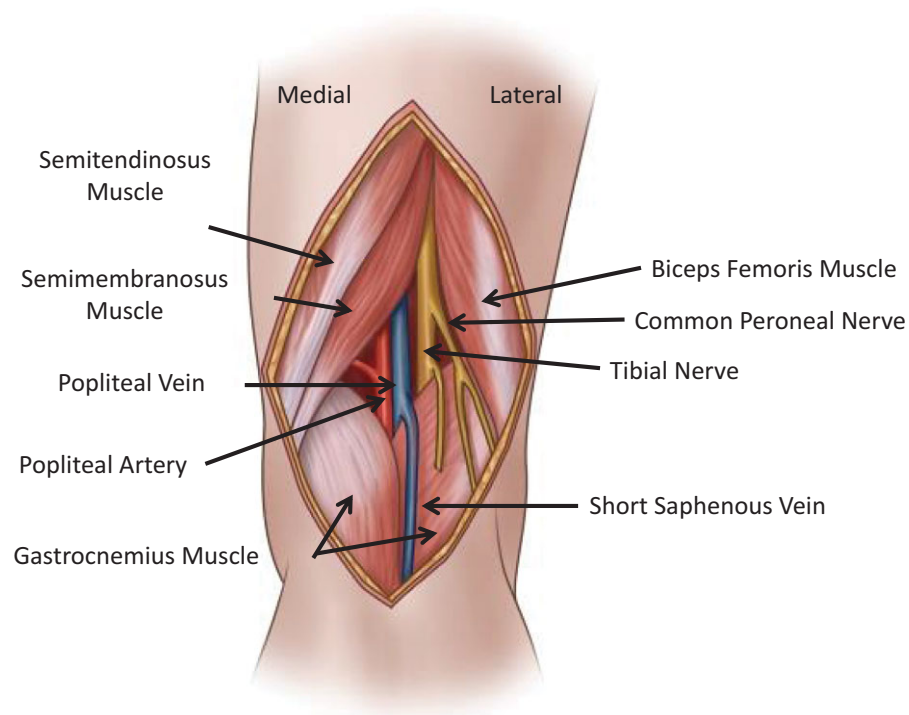
Popliteal Vessels

Demetrios Demetriades and Gregory A. Magee

Surgical Anatomy

- The popliteal fossa is diamond-shaped and its borders are formed by the semimembranosus and semitendinosus muscles superomedially, the biceps femoris muscle superiolaterally, the medial head of the gastrocnemius muscle inferomedially, and the lateral head of the gastrocnemius muscle inferiolaterally. It contains the popliteal artery and vein, the tibial and common peroneal nerves, and is covered by subcutaneous tissue and skin.
- The popliteal artery is the continuation of the superficial femoral artery after it passes through the adductor canal, an opening in the adductor magnus muscle, in the lower thirds of the thigh. It courses downward and laterally to the midline of the knee between the two condyles of the femur, into the popliteal fossa.
- The popliteal artery has three segments: supragenicular (above knee), midpopliteal (behind knee), and infragenicular (below knee). Exposure to each segment of the popliteal artery is distinct.
- The popliteal artery has superior and inferior genicular branches, which provide blood supply to the tissues surrounding the knee joint and provide important collaterals when there are occlusions of the superficial femoral or popliteal artery.
- Below the knee, the popliteal artery branches into the anterior tibial artery, followed by the peroneal branch about 2–3 cm lower, which itself then branches into the peroneal and posterior tibial arteries.
- The anterior tibial artery pierces the upper part of the interosseous membrane, courses in front of the membrane, under the extensor muscles of the anterior muscle compartment, and distally becomes the dorsalis pedis artery.
- The tibioperoneal trunk is the direct continuation of the popliteal artery and, after approximately 3 cm, branches to form the peroneal artery laterally and the posterior tibial artery medially. The peroneal and posterior tibial arteries lie in the deep posterior compartment of the leg posteriorly of the fibula and tibia, respectively.
- The posterior tibial artery continues directly to the ankle and lies superficially posterior to the medial malleolus, while the peroneal artery branches above the ankle to form collaterals to the dorsalis pedis and plantar branches of the posterior tibial artery in the foot.
- The popliteal vein lies posterior to the artery (more laterally superiorly to more medially inferiorly). The tibial nerve is lateral and posterior to the artery.

(a)



(b)

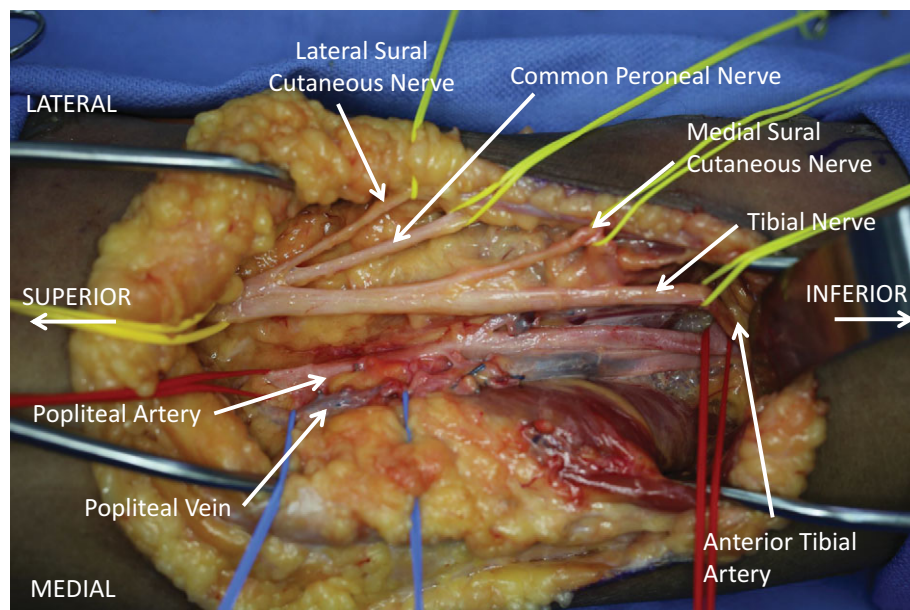


Figure 41.1 (a) Anatomy of the right popliteal fossa posterior view. The popliteal vein and tibial nerve are more superficial to the popliteal artery. (b) Anatomy of the right popliteal fossa posterior view: Note the close association of the popliteal vessels to the tibial nerve and common peroneal nerve. (c) Right popliteal artery posterior view. The anterior tibial artery pierces the upper part of the interosseous membrane (circle) and courses in front of the membrane in the anterior muscle compartment. The popliteal artery then becomes the tibioperoneal trunk, which bifurcates into the peroneal (fibular) and posterior tibial arteries.

(c)

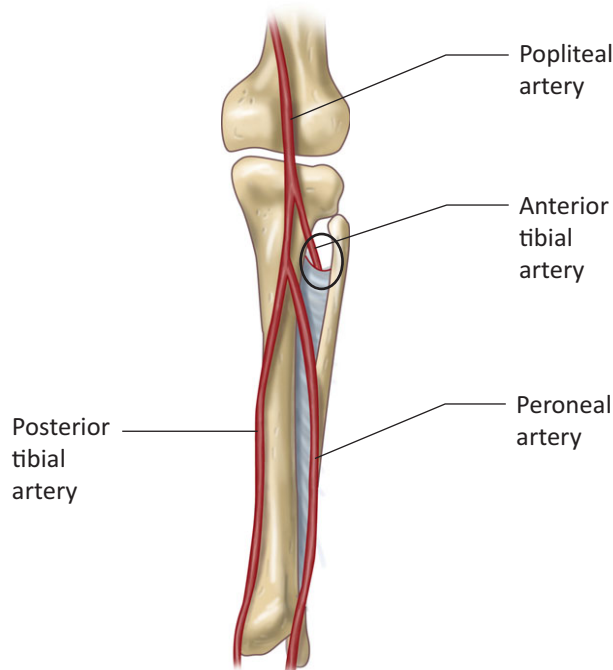


Figure 41.1 (cont.)

General Principles

- Popliteal artery injury is the most limb threatening peripheral vascular injury and it is associated with a high incidence of lower extremity amputation.
- Prognostic factors affecting limb salvage include: time interval between injury and treatment with a goal of less than 6 hours, mechanism, associated soft tissue, venous and nerve injuries, and chronic vascular disease.
- Posterior dislocation of the knee is associated with an approximately 20% incidence of popliteal arterial injury. Reduce the dislocation without delay and always evaluate pulses and measure the ankle brachial index (ABI). An ABI <0.9 should be evaluated further with a CT angiogram because an arterial duplex is often impractical when the patient is in pain or has orthopedic hardware that limits the evaluation.
- “Hard signs” of vascular injury include active hemorrhage, expanding or pulsatile hematoma, bruit or thrill, absent pulses, and distal ischemia as characterized by mottling or cyanosis, coolness, or decreased sensation or motor of the foot.
- Most popliteal artery injuries, due to firearm injuries or blunt trauma, require reconstruction with interposition or bypass vein graft. In rare occasions after a stab wound, a primary repair may be possible.
- In the presence of associated major orthopedic fractures, the blood flow can be restored with a temporary,

intravascular shunt. Following orthopedic fixation, the definitive vascular reconstruction can be performed.

- For patients requiring damage control or where the surgeon skillset is insufficient to perform definitive reconstruction, vascular shunting is the preferred method of restoring flow. Always use a Doppler probe to confirm flow through the shunt. Ligation should not be performed due to the high rate of limb loss.
- Prior to placing the intravascular shunt, a thrombosed injury should be interrogated by gently passing a long 3 French Fogarty balloon catheter to extract thrombus. The Fogarty catheter should be passed both proximally and distally until there is no further thrombus removed. If systemic anticoagulation with unfractionated heparin is not feasible due to coagulopathy, the proximal and distal ends of the artery should be flushed with heparinized saline, or at least saline, prior to placement of the shunt.
- On-table completion angiography should be performed if a palpable pulse is not restored following vascular reconstruction, as not all thrombus may have been removed.
- The lower extremity should always be evaluated clinically and in the appropriate cases with pressure measurements. A four compartment fasciotomy should be performed in all cases of clinical compartment syndrome, and compartment pressures >30 mmHg. Routine prophylactic fasciotomy is not indicated. However, prophylactic fasciotomy should be considered liberally in patients where close observation is not possible, such as long transportation or austere environments.

Special Instruments

- Headlight, magnifying loupes are helpful.
- Major vascular tray, vessel loops, long 3 French Fogarty catheter, sterile Doppler probe, Argyle or Pruitt-Inahara shunts.
- Device to measure muscle compartment pressures.
- Heparinized saline for regional heparinization (5,000 units heparin in 100 mL saline), papaverine for topical application, and water-soluble contrast.

Positioning

- Supine position with the hip flexed, abducted, and externally rotated, and the knee flexed and supported by a sterile bump.
- Full skin preparation of the injured leg and the contralateral groin, in case of need of autogenous vein harvesting.
- If an external bone fixator is needed, it should be placed after a temporary arterial shunt has adequately restored distal flow, with the knee in a slightly flexed position to enable proper vascular exposure.



Figure 41.2 Position for exposure of the left popliteal vessels: Supine position with the hip flexed, abducted, and externally rotated with the knee flexed and supported with a bump.

Incision

- The supragenicular, midpopliteal, infragenicular segments of the popliteal artery have distinct incisions and exposures.
- Medial exposure of the supragenicular (above the knee) popliteal artery begins with a longitudinal incision along the groove between the vastus medialis and sartorius muscles, which is about 1 cm posterior to the femur.
- Medial exposure of the infragenicular (below the knee) popliteal artery is via a longitudinal incision 1 cm posterior to the tibia from the medial tibial condyle for the proximal third of the leg.
- The midpopliteal (behind the knee) artery can be exposed via a posterior (the patient is in prone position) or medial approach, but in the setting of trauma, the medial approach is the most practical. The medial approach to the midpopliteal artery requires an incision that connects the supragenicular and infragenicular incisions described above.

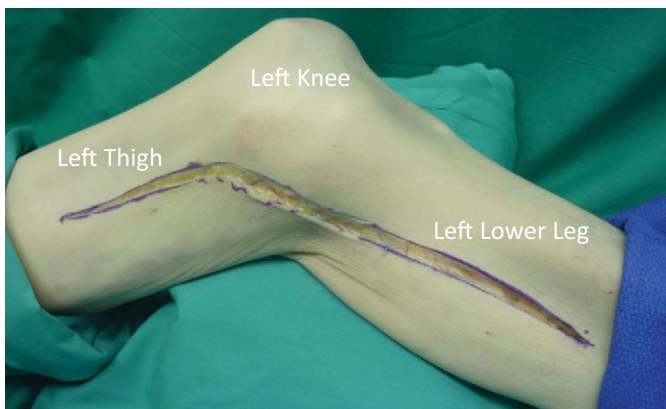


Figure 41.3 The incision starts about 1 cm posterior to the femur, continues distally, across the knee fold onto the distal lower extremity, approximately 1 cm posterior to the tibia.

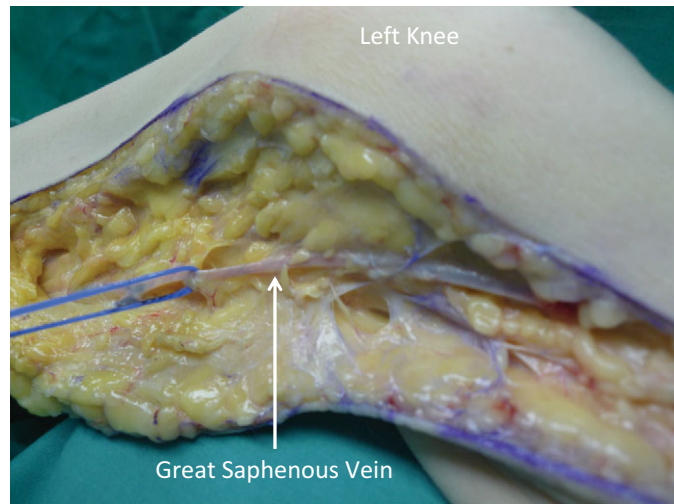


Figure 41.4 Isolation and preservation of the great saphenous vein is essential for venous drainage of the extremity when the popliteal vein is injured and ligated.

Exposure

- Take care to identify and preserve the great saphenous vein while dividing the subcutaneous tissue and fascia – it improves venous drainage of the extremity in the setting of popliteal venous injury with ligation, or may be needed for vascular reconstruction.
- For exposure of the popliteal artery above the knee, retract the sartorius muscle posteriorly to reveal the fatty plane posterior to the femur, which contains the supragenicular popliteal neurovascular bundle.

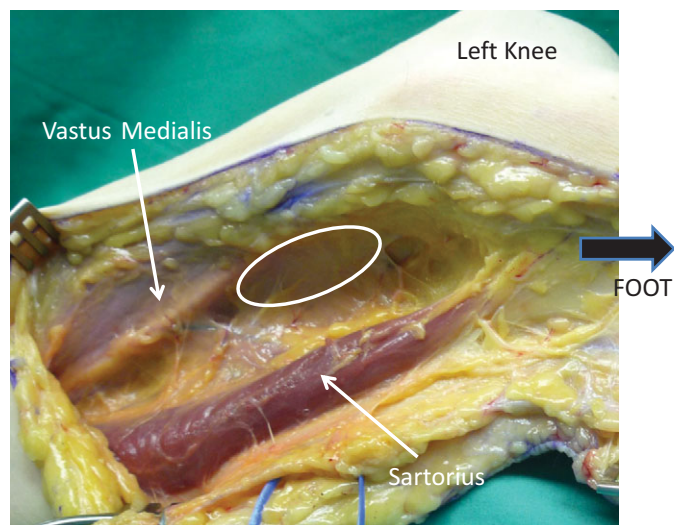


Figure 41.5 Exposure of the left above knee popliteal artery. The fascia of the thigh has been divided and the sartorius (inferiorly) and the vastus medialis muscle (superiorly) have been exposed. The supragenicular popliteal vessels are located in the fatty tissue plane just inferior to the distal shaft of the femur (circle).

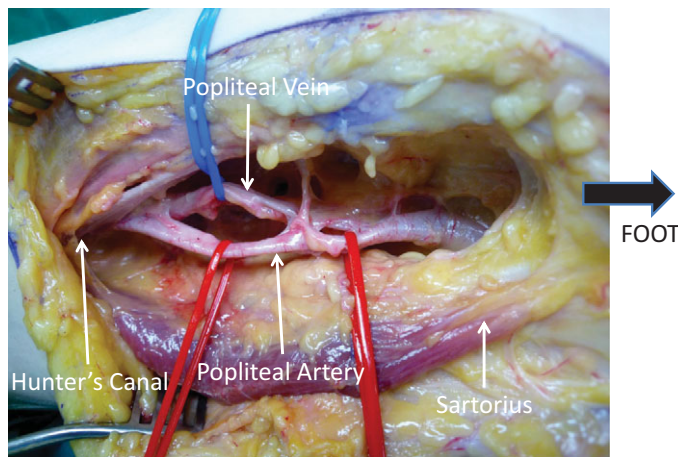


Figure 41.6 The supragenicular popliteal artery (encircled by red vessel loops) and popliteal vein exposed (blue vessel loop) with their accompanying genicular branches. Note the anatomical relationship of the two vessels, with the artery being medial to the vein above the knee.

- Retract the medial head of the gastrocnemius posteriorly and divide the tibial attachments of the soleus to reveal the infragenicular popliteal neurovascular bundle.
- The tendons attached to the medial knee, including the semimembranosus, the semitendinosus, and the gracilis muscles, can be divided if exposure of the midpopliteal artery is desired. They should be tagged proximally and distally with different color sutures to allow their reapproximation during closure of the wound for optimal functional results.
- Above the knee the popliteal artery is encountered first, as it is the most medial structure, followed by the popliteal vein, and then the tibial nerve as the dissection continues laterally. The vein should be dissected off the artery and retracted to expose the artery.
- Dissection can continue proximally, if required, until the popliteal artery crosses through the adductor (Hunter's) canal.
- There are several genicular branches of the popliteal artery that should be maintained because they provide important collaterals.
- Below the knee, the anterior tibial artery branches laterally (away from the exposure) and immediately crosses the interosseous membrane between the tibia and fibula. Exposure of the anterior tibial artery thereafter requires a separate longitudinal incision in the anterior compartment.
- Following branching of the anterior tibial artery, the tibioperoneal trunk continues inferiorly in a straight line for about 3 cm before it bifurcates into the posterior tibial artery and peroneal artery, which travel directly posterior to the tibia and fibula, respectively.

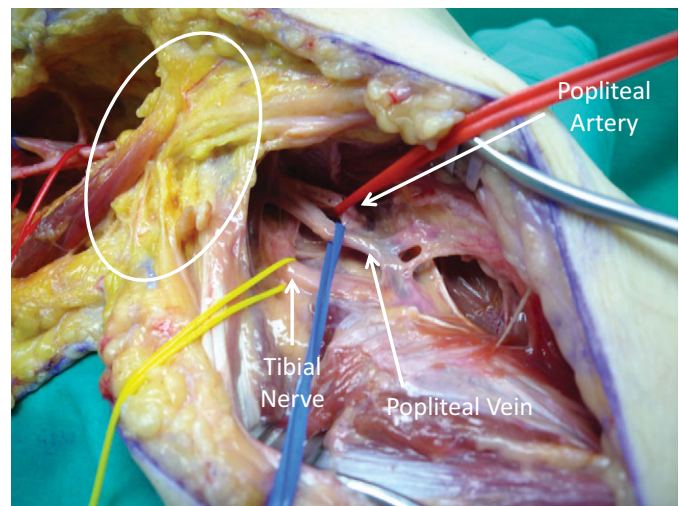


Figure 41.7 Exposure of the infragenicular popliteal artery. The pes anserinus (composed of the sartorius, gracilis, and semitendinosus tendons) (circle) has been left in place to provide orientation. The soleus muscle has been taken down from the tibia to allow exposure of the popliteal vein (blue vessel loop), the popliteal artery (red vessel loop), and the tibial nerve (yellow vessel loop). This is the order in which they are encountered during the dissection from medial to lateral.

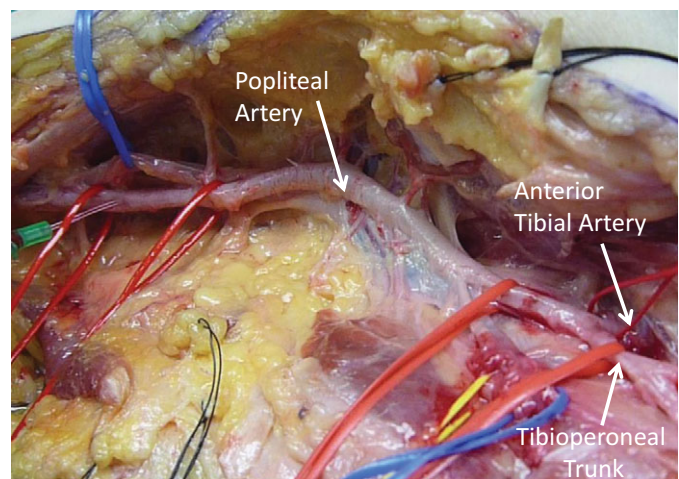


Figure 41.8 Exposure of the entire popliteal artery. The pes anserinus has been divided with each of the ends marked after division with silk ties to allow their reapproximation after the vascular repair. The divisions of the popliteal artery into the tibioperoneal trunk and the anterior tibial artery below the knee are marked with red vessel loops.

Management of the Injured Vessel

- After obtaining proximal and distal control, the injured portion of the vessel is exposed.
- A long 3 French Fogarty balloon embolectomy catheter is then advanced proximally and distally until all thrombus is removed. Heparinized saline is then injected into both ends of the artery.

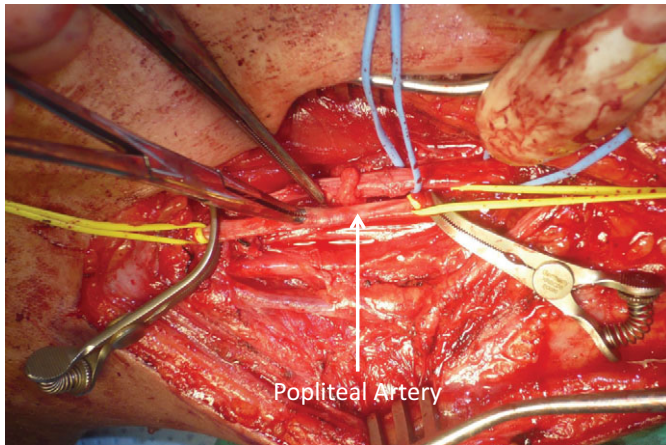


Figure 41.9 Proximal and distal control of the arterial injury with bulldog clamps.



Figure 41.10 For popliteal artery repair, the reversed autologous venous graft is the only conduit that should be utilized.

- Small lacerations of the artery can be repaired primarily. However, in the majority of cases, reconstruction with a reverse saphenous vein interposition graft is necessary.
- Use Potts scissors to trim the proximal and distal ends of the artery until there is healthy intima.
- The saphenous vein graft is harvested and prepared as described in the [Chapter 42](#), “Saphenous Vein Harvesting.”
- Spatulate the arteries proximally and distally and vein conduit to create a wide, tension-free anastomosis using a running or interrupted monofilament 5-0 or 6-0 polypropylene suture. The needle should pass from the intima to adventitia on the artery side in order to minimize the risk of an intimal dissection.
- The proximal anastomosis is performed first and flow through the graft is checked, prior to performing the distal anastomosis.

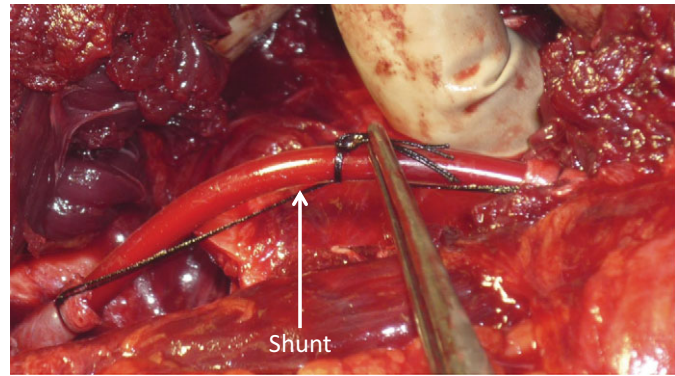


Figure 41.11 A temporary shunt can be utilized in damage control setting or to restore perfusion during the vein graft harvest or orthopedic interventions.

- Small caliber arteries can be dilated by gently inflating a Fogarty catheter intraluminally. Papaverine can be used topically to counteract vasospasm. Alternatively, nitroglycerin can be injected into the arteries in 200 mcg aliquots to reduce vasospasm.
- Confirm distal flow by palpating a pulse in the posterior tibial and dorsalis pedis arteries distally and use a sterile Doppler probe to confirm.
- If the patient is profoundly unstable or orthopedic fixation is required, a temporary shunt may be placed followed by arterial reconstruction. Choose the type of shunt you are most familiar with. If an Argyle shunt is used, do not cut the shunt as its ends are designed to be atraumatic. Argyle shunts should be secured proximally and distally using a moist umbilical tape with Rummel tourniquets or with 0 silk ties. Secure a silk tie around the middle of the Argyle shunt and tie each end to the silk ties on the proximal and distal artery to prevent dislodgement. Pruitt-Inahara shunts are secured using its proximal and distal intraluminal balloons. Always confirm flow in the shunt using a Doppler probe.

Other Considerations

- Completion angiography should be performed if the dorsalis pedis and posterior tibial arteries are not palpable after vascular repair or reconstruction.
- Before, during, and after the operation, all four muscle compartments of the leg should be evaluated for signs and symptoms of compartment syndrome. In the appropriate cases, if there is any clinical doubt, compartment pressures should be measured. Therapeutic four compartment fasciotomies should be performed in cases with compartment syndrome. Prophylactic fasciotomy should be considered in cases where close and continuous observation is not possible. Monitor serum creatinine kinase (CK) levels postoperatively for occult compartment syndrome.

- Devitalized tissue from associated extensive soft tissue trauma should be debrided and the vascular repair should be covered with surrounding healthy tissues.

Pitfalls

- Failure to allow a 30° flexion when applying an external fixator for fracture stabilization makes access to the popliteal vessels very difficult.
- Preservation of the saphenous vein during exposure of the popliteal vessels is important, as it can provide improved venous drainage when the popliteal vein is injured and ligated, or may be needed for vascular reconstruction.
- In exposing the supragenicular popliteal artery, the sartorius muscle must remain posterior to the dissection plane in order to locate the artery.
- Failure to debride all devitalized tissues and cover the anastomosis at the end of the procedure may result in infection, anastomotic blowout, and graft failure.
- Arterial repair or reconstruction must be performed without tension. In cases of clean laceration, mobilization of the proximal and distal segments of the artery may allow primary anastomosis. In most cases, however, a reversed interposition vein graft is required.
- Failure to reapproximate the divided tendons may result in knee instability.
- Perform routine postoperative monitoring of serum CK levels. Persistently rising CK levels in patients without fasciotomy is consistent with compartment syndrome and fasciotomy should be performed emergently. Persistently elevated CK in patients with fasciotomy suggests incomplete fasciotomy or missed muscle compartment(s). These patients should return to the operating room for exploration.

Harvesting of Saphenous Vein

Aaron Strumwasser and Gregory A. Magee

Surgical Anatomy

- The lower leg venous system consists of the superficial (greater saphenous vein) and deep (femoral vein) systems. Duplicated saphenous systems exist in the calf and thigh in approximately 25% of patients.
- Distally, the greater saphenous vein can be found anterior to the medial malleolus. It crosses the tibia, runs medial to the knee, and ascends into the medial and posterior segment of the thigh as it descends medially into the common femoral vein in the groin (saphenofemoral junction).
- In the thigh, the greater saphenous vein lies deep to the fascia (unlike accessory veins or tributaries). This may help discriminate the veins of the thigh during dissection.
- In the proximal aspect of the thigh, the greater saphenous vein runs into the confluence of the superficial circumflex iliac vein, superficial inferior epigastric vein, and external pudendal veins to create the saphenofemoral junction. A useful anatomic landmark for the saphenofemoral junction is two fingerbreadths inferior and medial to the pubic tubercle.



Figure 42.1 Mark the course of the saphenous vein in the medial aspect of the thigh with a marking pen.



Figure 42.2 Location of the inguinal ligament from the anterior superior iliac spine to the pubic tubercle. The saphenofemoral junction is located two fingerbreadths inferior and two fingerbreadths, medial to the pubic tubercle.

General Principles

- Autologous vein graft is preferred to prosthetic graft, typically expanded polytetrafluoroethylene (ePTFE), in most locations, if there is a reasonable size match. A few notable exceptions to this are the aorta, common carotid, and subclavian arteries, if there is a clean field.
- In the setting of a lower extremity vascular injury, use of the contralateral saphenous vein has been historically recommended because this strategy maintains venous collaterals and may theoretically reduce venous hypertension. This dogma has more recently been challenged as ipsilateral vein is used preferentially in elective lower extremity bypass.
- Reversal of the vein is the most expeditious technique; however, some prefer nonreversal of the vein graft with the use of valvulotomy, especially if there is a significant size mismatch from the vein conduit to the recipient artery.
- Careful handling of the vein graft is essential to prevent injury and subsequent graft failure.

- Always leave the graft in situ until the proximal and distal sites for arterial anastomoses are properly exposed and deemed appropriate for bypass so as to ensure the vein graft is of adequate length and caliber.

Patient Preparation and Positioning

- Standard trauma prep-and-drape.
- Keep the room warm and extremities covered to minimize peripheral venous vasoconstriction (up to the point of surgical preparation).
- Sterile “bump” to prop up the knee for easier exposure of the saphenous vein and popliteal or tibial recipient arteries if desired.

Equipment

- Vascular tray and suture (5-0 and 6-0 double-armed polypropylene)
- Ultrasound with 8 MHz probe (useful, but not absolutely necessary to mark out course of saphenous vein)
- Fogarty balloons (size 3, 4, 5 French depending on artery size)
- Vessel loops
- Coronary dilators (2, 2.5, 3 mm)
- Heparinized balanced electrolyte solution (5,000 units in 100 mL saline)
- Topical papaverine
- Nitroglycerine (50–200 mcg/mL aliquots) for intraluminal injection in the case of severe vasospasm

Surgical Technique

- The hip should be flexed, abducted, and externally rotated and the knee should be flexed to better expose the great saphenous vein, with a bump to expose the vessels of the groin and medial thigh.



Figure 42.3 Placing a sterile bump under the knee with knee flexion, hip flexion, abduction, and external rotation enables easier exposure of the great saphenous vein.



Figure 42.4 Make a vertical incision along just medial of the femoral vessels, two fingerbreadths lateral and inferior of the pubic tubercle.

- Preoperative ultrasound localization of the saphenofemoral junction may help identify the appropriate place to make an incision. Look for presence of intraluminal echoes, thrombus, webs, or venous injury from trauma. Access the vessel caliber —3 mm or greater is desired.
- The great saphenous vein, just beyond the saphenofemoral junction, can be reliably found two fingerbreadths inferior and medial to the femoral artery. A vertical incision for harvesting should start here. Follow the greater saphenous vein superiorly to the saphenofemoral junction.
- Very delicate and minimal manipulation of the vein is critical to reduce endothelial damage that can contribute to early graft failure.
- Side branch ligation should be done between ties (or clips on the nongraft side) and away from the lumen of the vessel to minimize stenosing the conduit and allow for dilation when pressurized by arterial inflow.

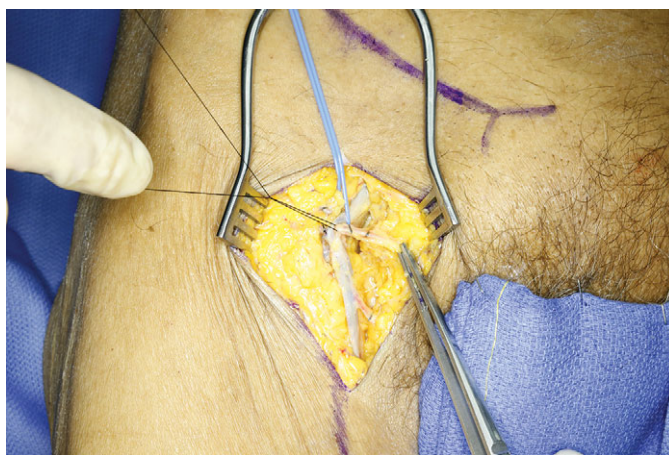


Figure 42.5 Bluntly spread the subcutaneous fat to encounter the great saphenous vein.



Figure 42.6 Identify and ligate the branches of the saphenous vein as it courses into the femoral vein.

- Identify the saphenofemoral junction to ensure you have not identified the accessory saphenous vein.
- Extend incision along the great saphenous vein. Ligate side branches between ties as they come. Use a self-training retractor to help with exposure.
- Mobilize the great saphenous vein distally for the length needed. Verify that the vein is of adequate quality (diameter and length) for grafting.

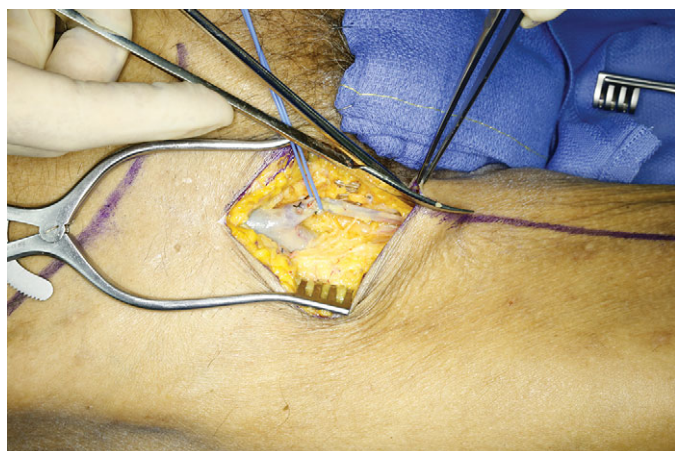
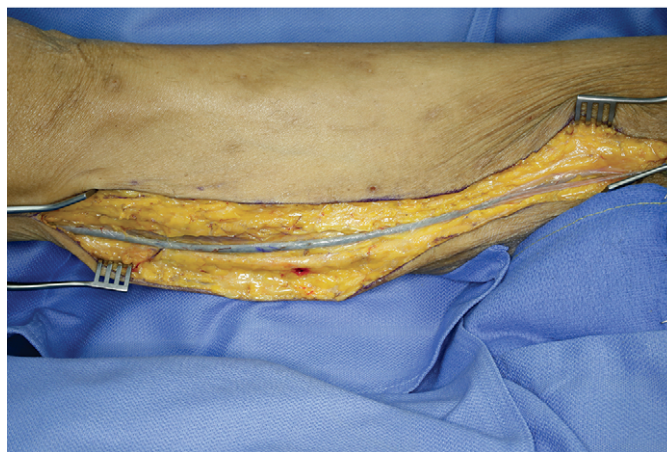


Figure 42.7 Identify the saphenofemoral junction to ensure that it is not the accessory saphenous vein.

(a)



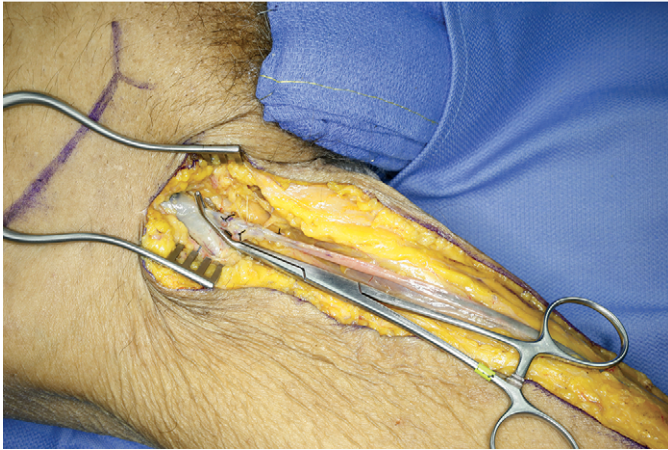
(b)



Figure 42.8 (a, b) Extend incision along the great saphenous vein. Ligate side branches between ties as they come. Use a self-training retractor to help with exposure.

- Adventitial bands of the vein may need to be lysed in some locations if the graft does not dilate well when pressured.
- Ligate the saphenous vein proximally and distally only after the proximal and distal arterial targets have been confirmed to be appropriate sights for bypass, so as to ensure to harvest the necessary length of vein.

(a)



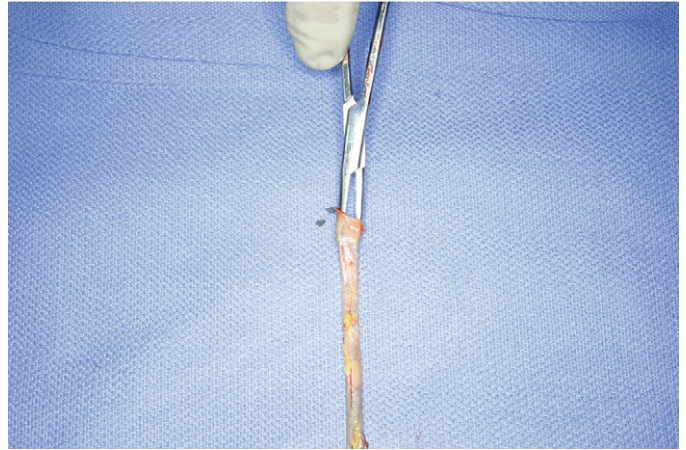
(b)



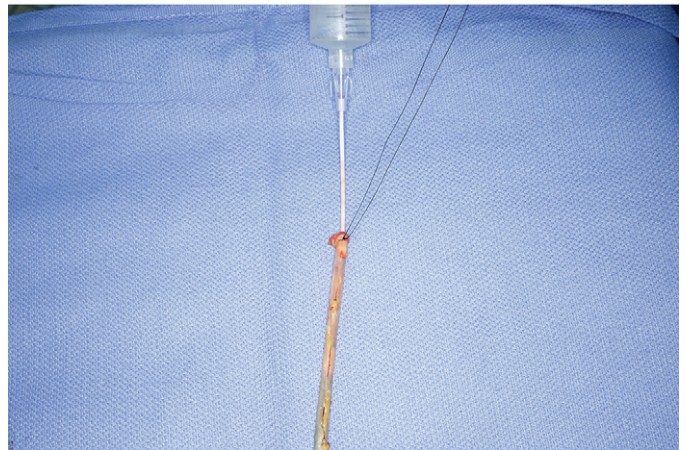
Figure 42.9 (a, b) Divide the GSV just distal of the saphenofemoral junction and suture-ligate the proximal vein, and ligate the GSV distally with a silk suture.

- Mark the caudal side of the vein graft. Cannulate the caudal end of the graft with an olive syringe tip and secure in place with a silk suture. Pressurize the graft with a heparinized, balanced electrolyte solution to evaluate for leaks, luminal irregularities, stenosis, and size discrepancy. Do not cause excessive distention of the native graft as this can cause endothelial damage that will not be visible on the external surface of the graft.

(a)



(b)



(c)

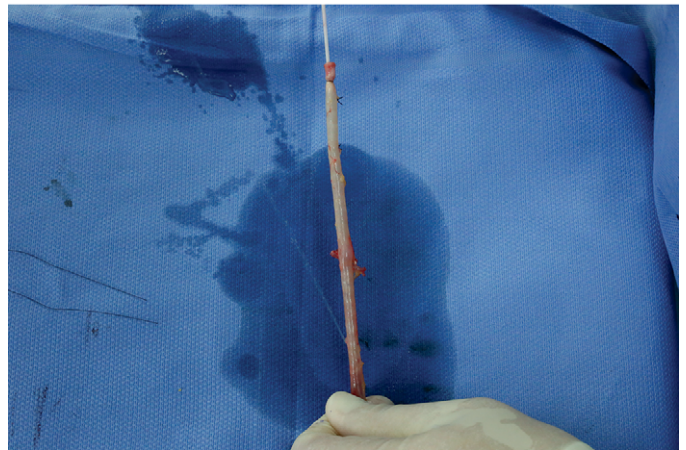


Figure 42.10 (a–c) Prepare the vein by cannulating the distal end with an angiocath or olive tip and flush with a heparinized, balanced electrolyte solution to evaluate for leaks. Repair leaks from side branches with 6-0 polypropylene sutures.

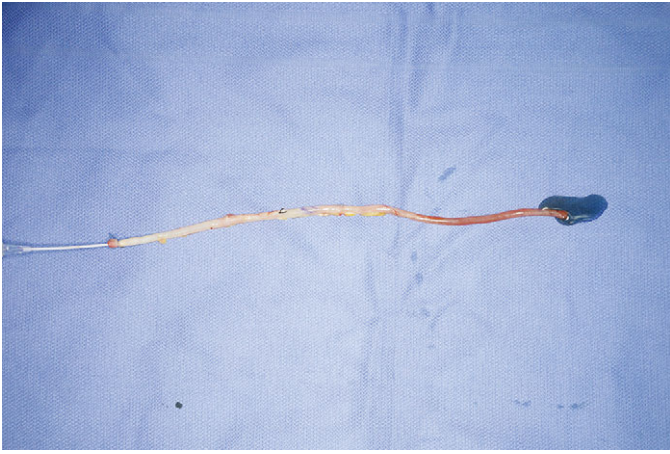


Figure 42.11 Ensure the vein dilates to sufficient diameter (at least 3 mm) and that the flow through the graft is adequate.

- Ensure the GSV dilates to a sufficient caliber (at least 3 mm), and assess that there is adequate flow through the graft without excessive resistance.
- Try to minimize the time from excision of the saphenous to implantation. Always keep graft in heparinized, balanced electrolyte solution or heparinized autologous blood prior to implantation.

Tips and Pitfalls

- Harvesting of the saphenous vein proximally at the groin is preferable to distally.
- Use of ultrasound localization (especially in the presence of previous groin incisions) is strongly recommended.
- The accessory great saphenous vein may be mistaken for the main saphenous vein, producing an inferior quality graft. The accessory vein usually runs anteriorly to the greater saphenous vein, is of smaller caliber and runs parallel to the main trunk of vein superficial to the fascia).
- Improper graft insertion (failure to reverse or lyse valves)
- Twisted, rotated graft during tunneling will result in thrombosis
- Kinked graft (failure to straighten and bend the knee when measuring graft length)
- Stenosed graft (diameter mismatch)
- Using clips to ligate side-branches of the saphenous vein graft (clips may come off during tunneling and when under arterial pressure, leading to bleeding)
- Excessive distention while evaluating the graft for leaks may cause endothelial damage to the graft and result in early graft failure.
- Failure to ligate major lymphatic channels that course deep with the femoral vessels (leading to lymphatic leak).

Lower Extremity Amputations

Jackson Lee, Jessica A. Keeley, and Stephen Varga

Surgical Anatomy

- Above and below the knee amputations require basic anatomy knowledge of the muscle compartments, nerves, and arteries of the lower extremity.
- The thigh has three compartments: anterior, posterior, and medial. The calf has four compartments: the anterior, lateral, or peroneal in addition to the deep and superficial posterior ones.
- The lower extremity is perfused by the superficial and deep femoral artery. The superficial femoral artery continues as the popliteal artery after exiting the Hunter's canal. The popliteal artery bifurcates into tibialis anterior artery and the tibioperoneal trunk. The tibioperoneal trunk gives the fibular artery and continues as the posterior tibial artery. The femoral and sciatic nerves provide innervation to the lower extremity.

General Principles

- The goal with amputation surgery is a functional extremity with a residual limb that successfully interacts with the patient's future prosthetic and external environment.
- The rule of preserving as much length as possible is not always applicable in the lower leg. Long leg stumps often do not heal well because of poor blood supply and do not tolerate prosthesis well.
- A short below-knee stump is preferable to knee dislocation, but a stump shorter than 6 cm may not be functional.
- Optimal above the knee amputation level is between 12 and 18 cm below the trochanter major.
- Use tourniquets to minimize blood loss. The cuff should not be placed directly over bony prominences, such as the head of the fibula or malleoli, to avoid the risk of direct nerve compression and damage. Elevation of the leg to empty the venous blood and reduce blood loss should be done before inflation of the tourniquet cuff. This process may be facilitated with the use of bandage or tourniquet exsanguinators. The inflation pressure is usually set at about 250 mm Hg in adults or about 100 mmHg above the systolic pressure.
- All nonviable or contaminated tissue must be removed and there must be sufficient arterial perfusion to allow healing.
- Sufficient soft tissues should be preserved to cover the end of the bone without tension. However, excessive amount of soft tissues may interfere with prosthesis fitting.
- The scars of weight-bearing stumps should preferably be posteriorly to the edge of the stump.
- Nerves are divided as high as possible and allowed to retract. They should be divided sharply and ligated with non-absorbable sutures to reduce the risk of formation of potentially painful neuromas. The ends of the nerves should be away from areas of pressure.
- Bone edges should be filed to remove any sharp edges.
- In closing the wound, always keep a myofascial layer between the bone and the skin.
- Wounds should be closed without tension and suture lines should be placed away from weight-bearing surfaces when possible.
- Drains can be used to reduce dead space and to drain residual bleeding.

Special Surgical Instruments

- Pneumatic tourniquet and bandage or tourniquet exsanguinator.
- Power saw or Gigli saw the division of the bone.
- Bone files or rasps are essential to smooth out bone edges.
- Compression wraps for post-operative dressings are helpful to decrease edema and to shape the stump for early fittings of prosthetics.

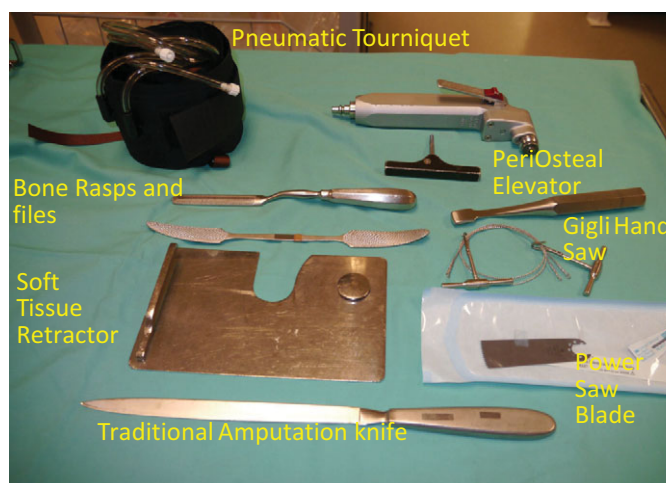


Figure 43.1 Essential instruments for amputations in trauma. Pneumatic tourniquet, bandage or tourniquet exsanguinators, power saw or Gigli saw, bone files or rasps.

Patient Positioning

- The patient is placed in the standard supine trauma position with both arms at 90° to allow anesthesia access to the upper extremities.
- The leg should be prepped circumferentially and pneumatic tourniquet applied proximal to the injury to minimize blood loss during the procedure. Padding or surgical towels can be placed under the thigh to allow for elevation of the extremity.
- The surgeon stands on the inner side of the leg for better view of the vessels and nerves.

Above-Knee Amputation

- The femur can be divided at any length necessary; most commonly this is at the junction of the middle and distal

third of the femur shaft for the optimal functional interaction with prosthetic limb (12–18 cm below the trochanter major).

- Start with applying a pneumatic tourniquet if there is enough femur length.
- Mark with skin pen a transversely oriented fish-mouth incision. The anterior and posterior tissue flaps may be equal or the anterior flap may be longer. The skin incision should be about 15 cm below the planned division of the bone.
- The skin and subcutaneous tissue should be divided circumferentially. The saphenous vein is identified in the medial aspect of the thigh and ligated,

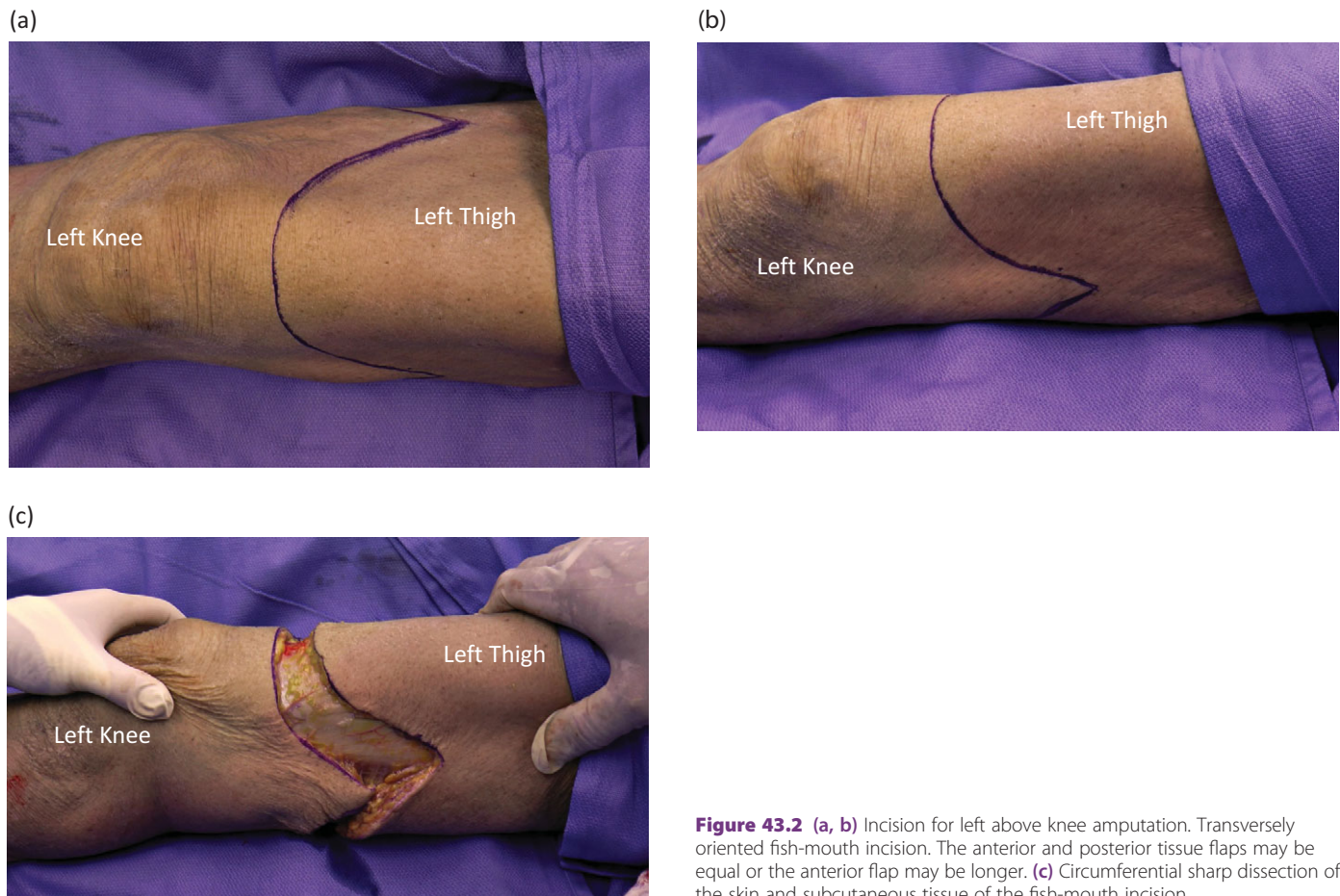
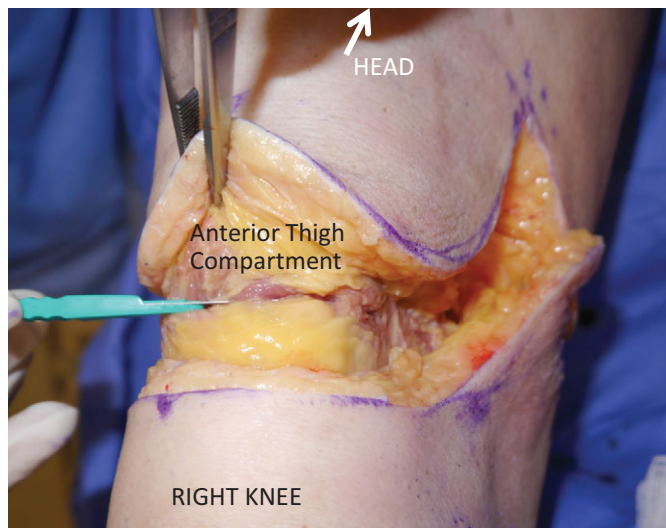


Figure 43.2 (a, b) Incision for left above knee amputation. Transversely oriented fish-mouth incision. The anterior and posterior tissue flaps may be equal or the anterior flap may be longer. (c) Circumferential sharp dissection of the skin and subcutaneous tissue of the fish-mouth incision.

(a)



(b)

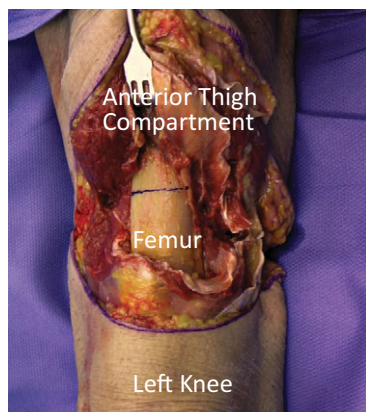


Figure 43.3 (a) The anterior thigh compartment muscles are sharply divided to the bone. (b) The anterior thigh compartment muscles are reflected proximally to expose the femur. The level of division of the femur is marked.

- The anterior thigh compartment muscles are sharply divided to the bone about 3–5 cm distal to the planned femoral osteotomy. The divided muscles are reflected proximally.

- The femoral artery and vein are identified deep to sartorius muscle and individually ligated and divided.
- The transverse osteotomy is performed with a Gigli or power saw and sharp edges should be filed down with the bone rasp
- The posterior thigh compartment muscles are sharply divided about 3 cm distal to the femoral osteotomy site. The deep femoral artery is ligated when encountered depending on the level of the amputation. The sciatic nerve is identified, divided sharply and ligated as high as possible.
- Periosteal elevator is utilized to separate periosteum from the bone.

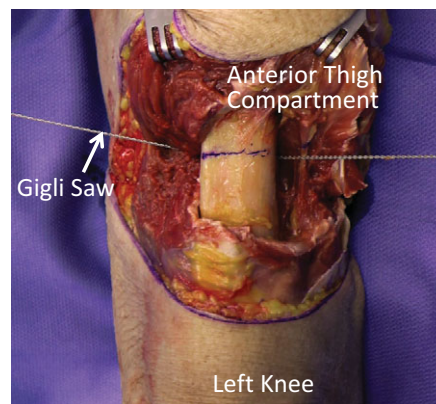


Figure 43.4 A Gigli saw is used to divide the femur transversely.

(a)

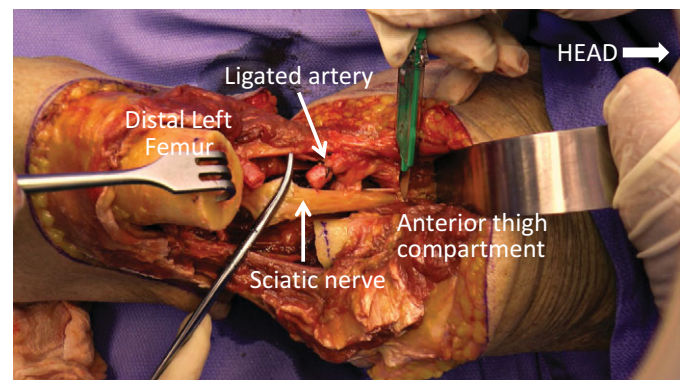
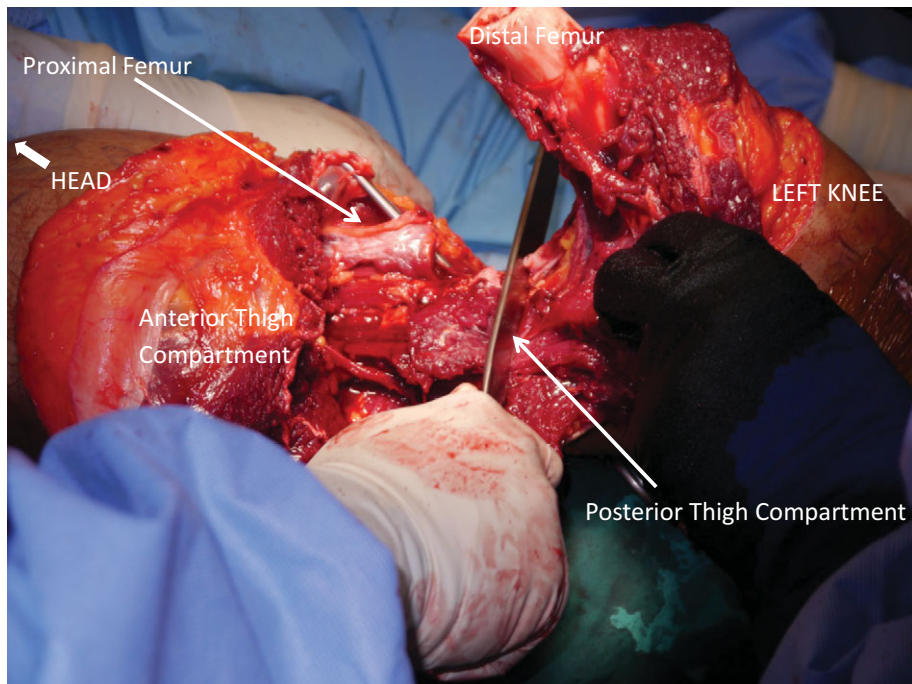
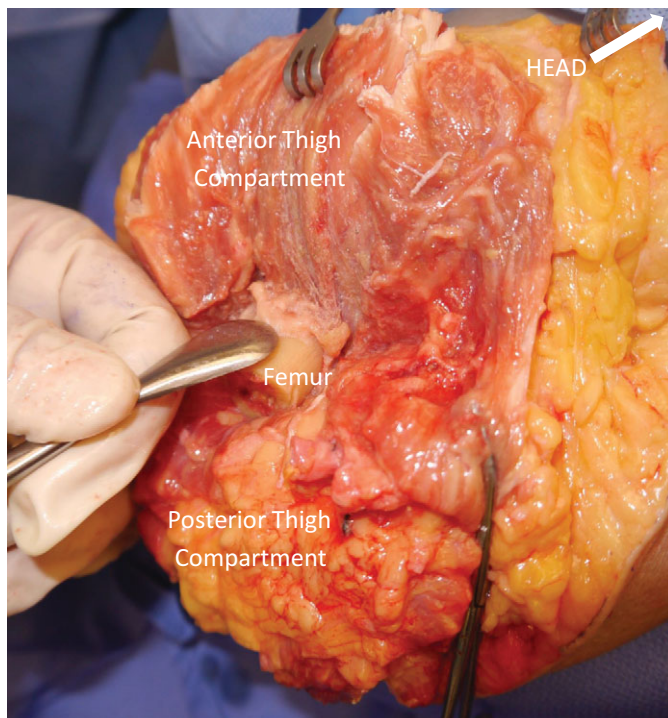


Figure 43.5 (a) Identification and ligation of the superficial femoral artery. Distal traction and division of the sciatic nerve. (b) Sharp division of the posterior thigh compartment muscles.

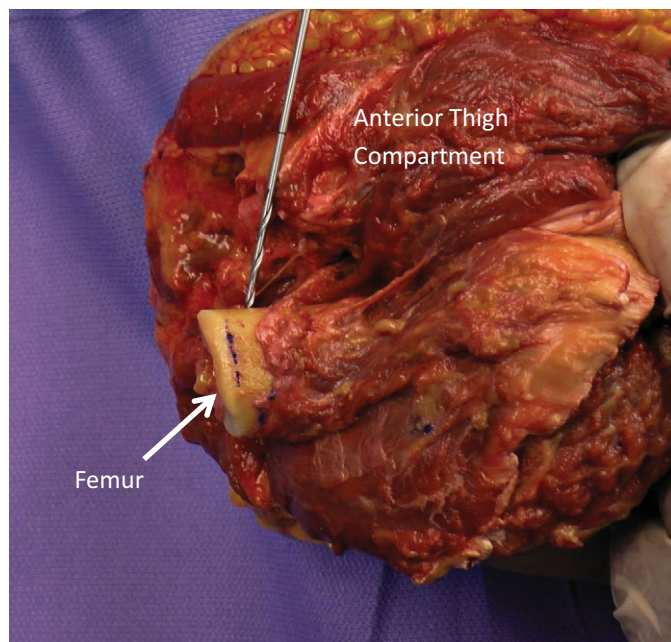
(b)

**Figure 43.5** (cont.)**Figure 43.6** Periosteal elevator is used to separate the periosteum from the femur in preparation for myodesis.

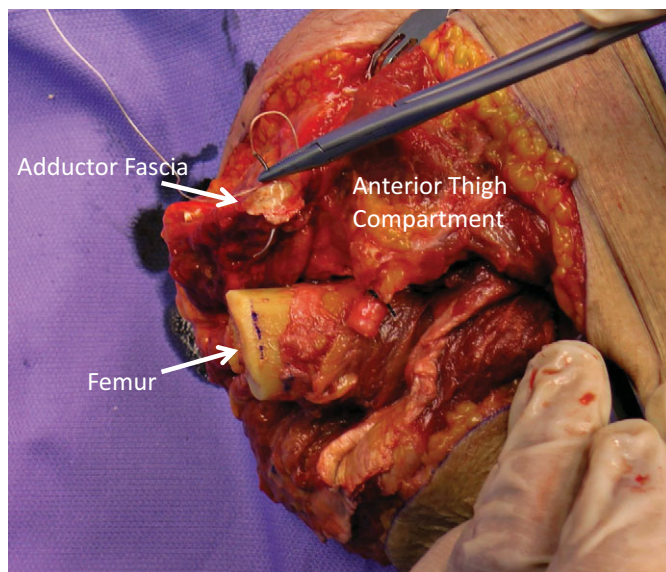
- Myodesis is performed to attach and stabilize muscles directly to bone facilitating fixed resistance against which a muscle can move, to maintain function, and to provide distal padding of the osteotomy. Myodesis is

performed by drilling four unicortical holes to the distal femur using 2.5 mm drill screw to attach the adductor and medial hamstring muscles to the bone with absorbable sutures.

(a)



(b)



(c)

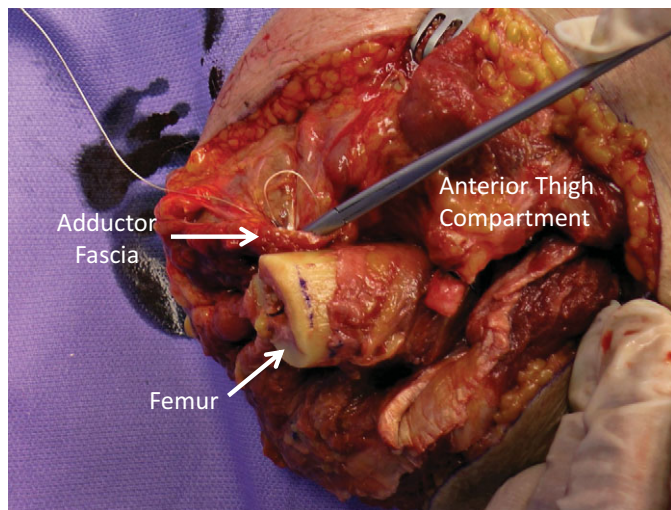


Figure 43.7 (a) Drilling of unicortical holes to the distal femur using 2.5 mm drill screw for myodesis. (b) Fascia of the adductor and medial hamstring muscles is identified and an absorbable suture is used to attach the fascia to the femur. (c) The adductor fascia is attached to the femur by passing the suture through the previously drilled unicortical holes.

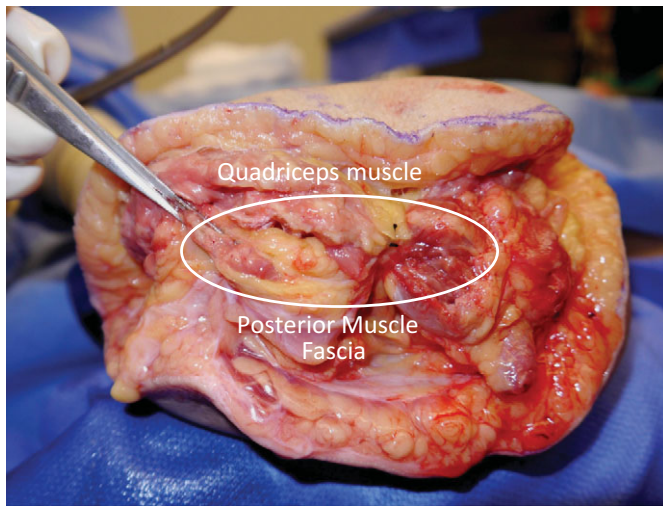


Figure 43.8 Myoplasty (white circle) over the femur. The quadriceps femoris is placed over the bone and sutured to the posterior fascia using interrupted absorbable sutures.

- Myoplasty is performed by bringing the quadriceps femoris over the bone and suture to the posterior fascia using interrupted absorbable sutures over the drains.
- The skin is then closed with staples or interrupted 3-0 nylon vertical mattress sutures without tension.

Technical Tips and Pitfalls

Preserve as much femoral shaft length as possible to improve function and prosthetic fit.

- When making the anterior and posterior flaps, ensure there is enough tissue for adequate coverage of the femur and that the flaps are able to come together without tension.
- Flex the patient's hip to check for tension on the skin suture line. If tension is present the femoral shaft requires further shortening.



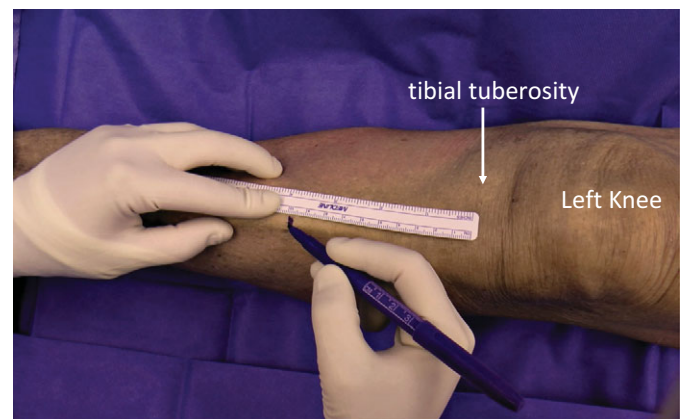
Figure 43.9 Completed above knee amputation.

- Perform myodesis of the adductor and medial hamstrings to the bone to prevent nonfunctional and unstable femoral stump.

Below-Knee Amputation

- The most commonly used amputation involves the creation of a long posterior myocutaneous flap.
- Mark the skin incision with a marking pen.
- Inflate the pneumatic tourniquet.
- The anterior skin incision is made transversely and located 10–12 cm or approximately one handbreadth below the tibial tuberosity and extended to both sides of the calf for a distance of about one-half of the calf circumference. Ligate the saphenous vein when encountered in the medial aspect of the leg.
- To construct the posterior flap, extend the skin incision along the vertical axis of the extremity for a length of one and a half times the transverse incision (12–15 cm). The posterior flap should be gently curved to reduce dog-ears in the closure.

(a)



(b)

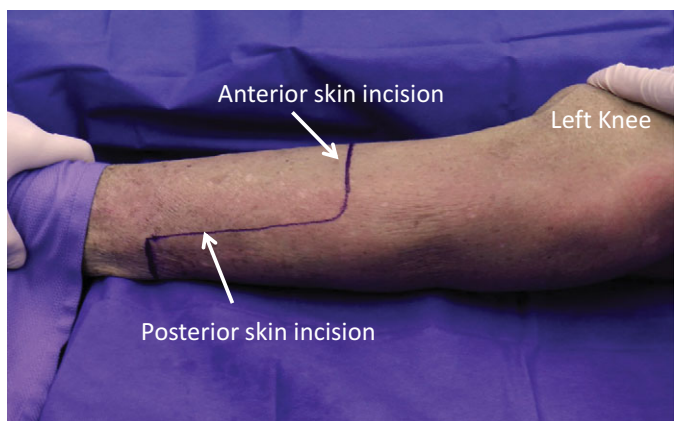


Figure 43.10 (a) Left below-knee amputation. The anterior skin incision is made transversely, about 10–12 cm or approximately one handbreadth below the tibial tuberosity and extended to both sides of the calf for a distance of about one-half of the calf circumference. (b) The posterior skin incision is marked along the vertical axis of the leg for a length of one and a half times the transverse incision (12–15 cm). The incision should be gently curved to reduce dog-ears in the closure.

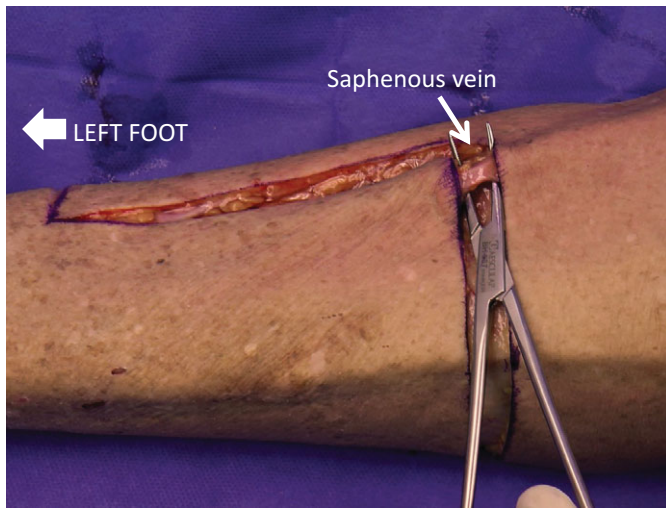


Figure 43.11 Identification and division of the saphenous vein in the medial aspect of the calf.

- The anterior compartment muscles are divided sharply in the same plane as the transverse skin incision, and dissection is carried down until the anterior tibial artery and vein with the deep peroneal nerve are identified. The vessels are suture-ligated with 2-0 silk sutures and the nerve is retracted and divided sharply.

A periosteal elevator is used to clear muscular attachments to the tibia and the interosseous membrane is divided sharply.

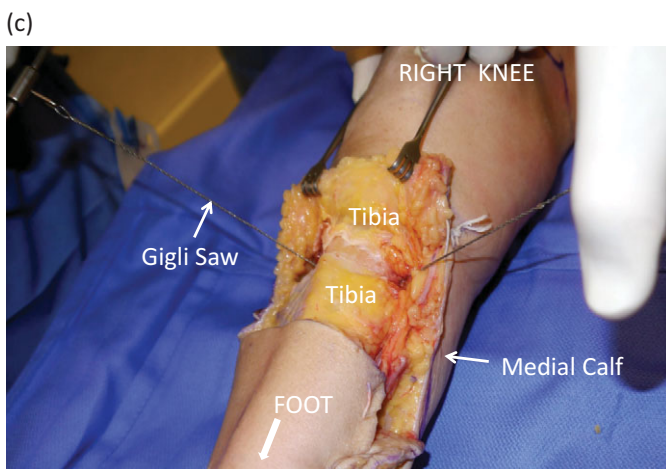
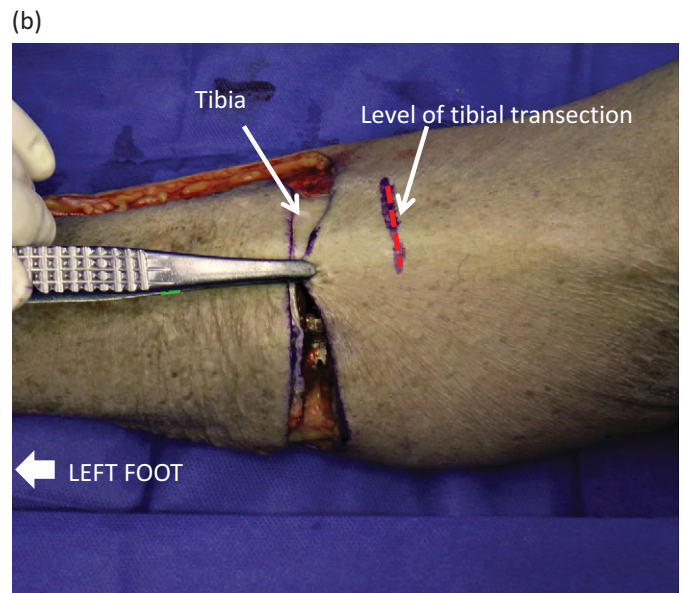
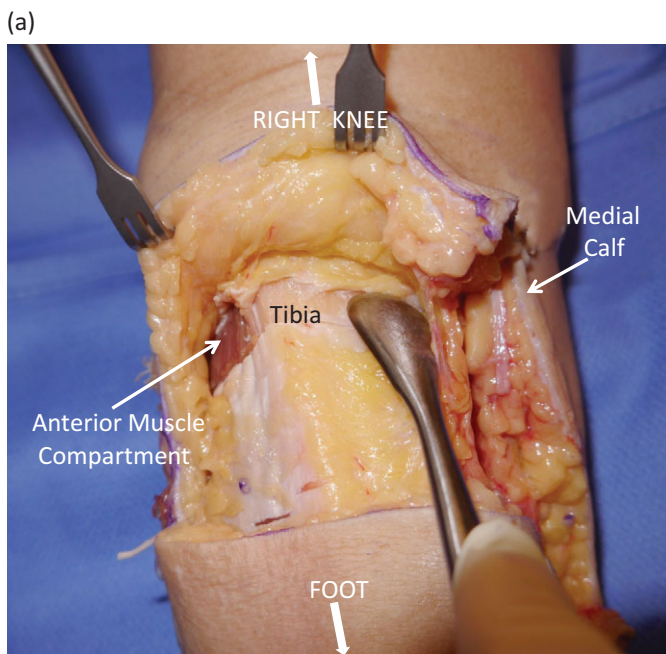
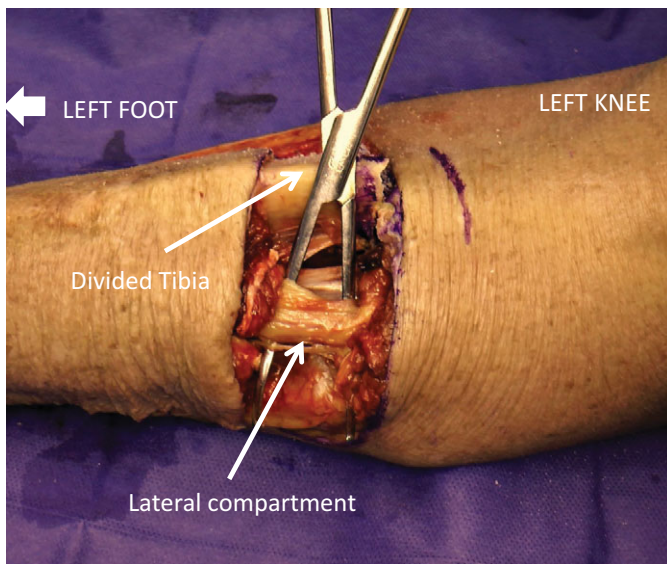


Figure 43.12 (a) Circumferential clearing of the tibia with periosteal elevator, from the muscular attachments. (b) The level of division of the tibia should be approximately 2 cm above the level of the skin incision. (c) Division of the tibia with a Gigli saw.

- The tibia is then divided using a power or Gigli saw proximal to the skin incision in a plane perpendicular to the long axis of the bone. The anterior lip of the tibia is then beveled and filed down to remove any sharp edges (Figure 43.12b, c).
- The lateral compartment muscles are divided sharply in the same plane as the transverse skin incision. The fibula is identified and cleared of its muscular attachments circumferentially with a periosteal elevator. The fibula is transected with the power or Gigli saw 2–3 cm proximal to the tibia transection; any sharp edges should be filed down. The fibula can be excised in young individuals.
- The posterior compartment muscles are divided in a plane below the distal tibia and fibula to create the posterior muscle flap. Remove enough of the soleus muscle to prevent excessive bulk or tension in the flap closure.
- The posterior tibial and peroneal vessels are identified and suture-ligated with 2-0 silk sutures. The tibial and peroneal nerves should be divided sharply under tension and allowed to retract.

(a)



(b)

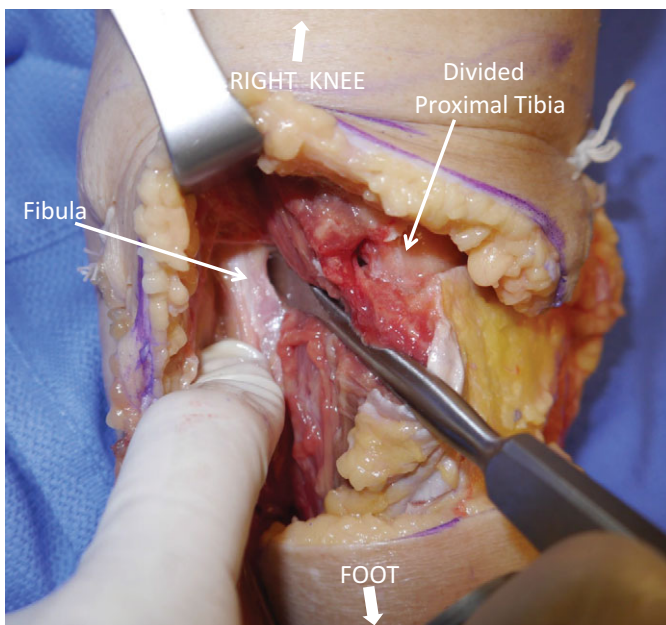
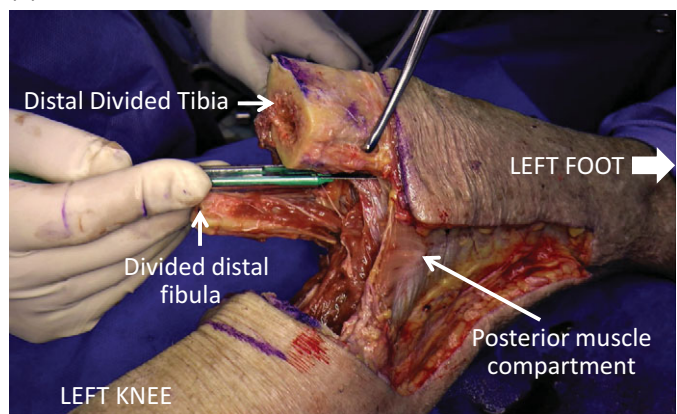


Figure 43.13 (a) The muscles of the lateral compartment are divided to expose the fibula. (b) Identification of the fibula with clearing of the soft tissue circumferentially with a periosteal elevator and division of the fibula 2–3 cm above the level of the divided tibia.

(a)



(b)

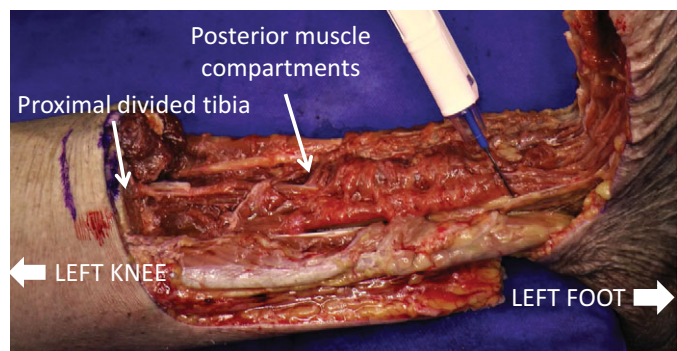


Figure 43.14 (a) Division of the posterior compartment muscles in a plane below the distal tibia and fibula sharply to create the posterior muscle flap. (b) The posterior muscle flap is divided at the level of the posterior skin division. (c) Firm traction on the tibial nerve, followed by sharp division proximally (red arrow). The nerve stump is then allowed to retract. (d) Beveling the anterior lip of the tibia (circle) to remove any sharp edges.

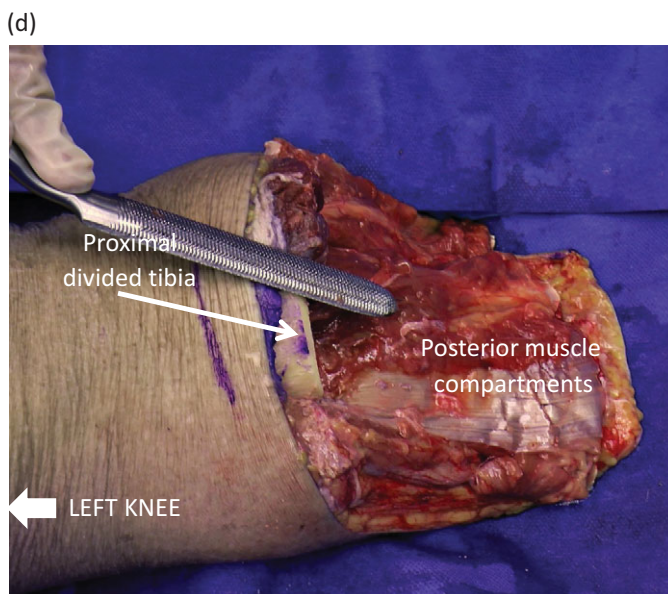
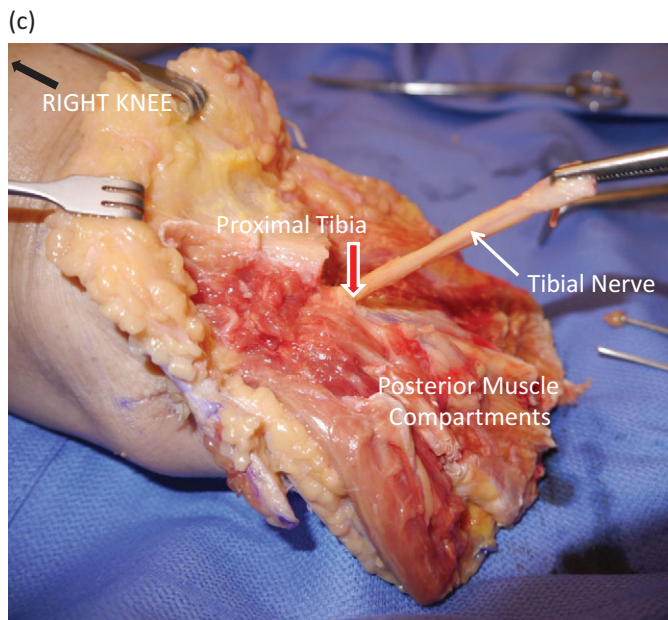


Figure 43.14 (cont.)

- The tourniquet should then be released and hemostasis checked and achieved with suture-ligation. The wound should then be irrigated and the posterior flap rotated over a drain to cover the tibia and fibula.
- The deep fascia is approximated with interrupted 2-0 absorbable sutures, ensuring a tension-free closure.

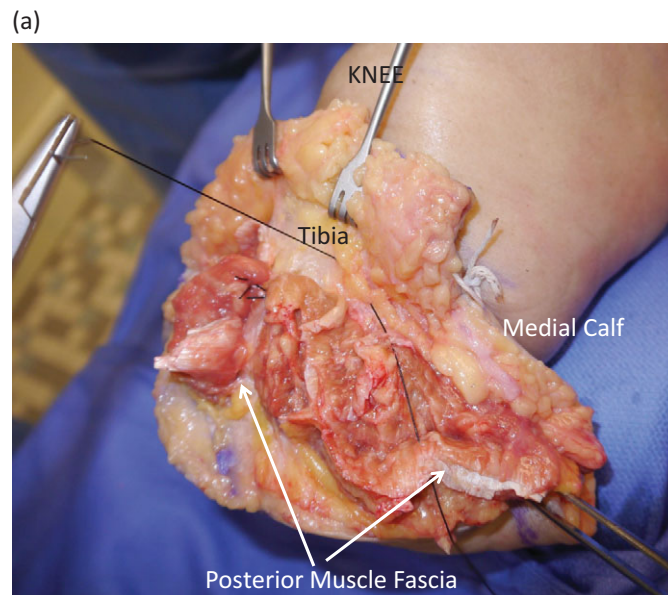


Figure 43.15 (a) Rotation of the posterior muscle flap with closure of the posterior muscle fascia over the tibia. (b) Completed below-knee amputation.

- The skin is closed with staples or interrupted 3-0 nylon vertical mattress sutures (Figures 43.15b).

Tips and Pitfalls

- Failure to make the posterior flap long enough to cover the tibia will place the suture line under tension and will not provide adequate soft tissue coverage of the bones.
- Failure to make a gentle curve of the posterior incision will result in excessive skin and dog-ears during the closure.

- Failure to transect the fibula 1–2 cm proximal to tibial transaction will result in pain if left too long or a conical stump if left too short, either of which will be difficult to fit with a prosthesis.
- Removing too much of the soleus muscle in the posterior flap will cause the soft tissue coverage of the bone to be too thin and may cause pain and irritation of the skin. Leaving too much of the soleus muscle will create a bulky stump and may add tension to the closure.
- Failure to place the nerves under tension and divide them sharply will prevent them from retracting and may result in neuroma formation.

Guillotine Amputation (Below Knee)

- The purpose of the guillotine amputation in the trauma setting is to quickly remove the mangled extremity in a damage control situation with the plan to return to the

operating room in the future for a staged operation. However, this type of amputation should be avoided and every effort should be made to preserve as much skin as possible.

Post-operative Care

- Apply petroleum gauze over the skin incision and wrap the stump in a soft gauze dressing with a mild compression wrap to help reduce edema and protect the wound from trauma. If needed, a semirigid removable dressing may be applied to help prevent contractures.
- Post-operative care of amputation patients requires multidisciplinary cooperation with rehabilitation medicine, physical therapy, psychiatry services, and the surgical team. All must work coherently to get the patient ambulatory and fitted with a permanent prosthesis as soon as possible.

Lower Extremity Fasciotomies

Elizabeth R. Benjamin and James Bardes

Surgical Anatomy

- The lower extremity fascial compartments include three gluteal, three thigh, four calf, and nine of the foot. These compartments contain muscles, nerves, and blood vessels.
- The compartments of the buttock include the gluteus maximus, the gluteus medius/minimus, and the extension of the fascia lata of the thigh into the gluteal region. The sciatic nerve is the only major neurovascular structure in the compartments of the buttock.
- The thigh has three compartments:
 - The anterior compartment contains the quadriceps femoris and sartorius muscles, as well as the femoral vessels and femoral nerve.
 - The posterior compartment contains the biceps femoris, semitendinosus, and semimembranosus muscles and the sciatic nerve.
 - The medial compartment contains the adductor muscle group and the gracilis muscle.
- The lower leg has four leg compartments:
 - The anterior compartment: Contains the tibialis anterior muscle, extensor hallucis muscle, extensor digitorum longus muscle, the anterior tibial artery, and the deep peroneal nerve.
 - The lateral compartment: Contains the peroneus longus and brevis muscles, and the superficial peroneal nerve.
 - The superficial posterior compartment: Contains the gastrocnemius muscle, soleus muscles, plantaris muscle, and the sural nerve.
 - The deep posterior compartment: Contains the flexor hallucis longus muscle, flexor digitorum longus muscle, tibialis posterior muscles, popliteus muscle, the posterior tibial artery, and the tibial nerve.
- The foot contains a total of nine compartments, including four interosseous (medial, lateral, deep, and superficial central) and the adductor hallucis compartments that may require decompression in crush injuries to the foot. The medial, lateral, and superficial compartments pass through the entire length of the foot, while the interosseous

compartments and the calcaneal compartments are confined to the forefoot and the hind foot, respectively.

General Principles

- Compartment syndrome is a limb- and, sometimes, life-threatening condition, and must be recognized quickly. Renal failure due to myoglobinemia and myoglobinuria is a common serious complication if the diagnosis or treatment is delayed.
- Extremity compartment syndrome may occur in patients with severe fractures, crush injury, ischemia due to vascular injury, venous outflow obstruction, circumferential burns, and constricting bandages or casts. On rare occasions, massive fluid resuscitation in trauma or burn patients may cause secondary compartment syndrome.
- The variables affecting the severity of the compartment syndrome include hypotension, duration of elevated compartment pressure, perfusion pressure, and individual susceptibility.
- With a clinical concern for compartment syndrome, there should be a low threshold for direct compartment measurements.
- The compartmental perfusion pressure is defined as the difference in pressure (mmHg) between the patient's diastolic blood pressure and measured compartmental pressure. A perfusion pressure of 30 mmHg or less is associated with a high risk of compartment syndrome.
- Compartment pressures >30 mmHg or perfusion pressures <30 mmHg should prompt an evaluation for emergency fasciotomy.
- Reversible muscular ischemia and neuropraxia occurs after 4–6 hours of ischemia. Irreversible muscular ischemia and axonotmesis occurs after 6 hours of ischemia.
- The anterior and lateral compartments of the calf are the most commonly affected by compartment syndrome.
- Limited skin incisions may result in inadequate decompression of the muscle compartments.
- The fasciotomy skin incisions should always be left open.
- After decompression of the compartments, the viability of the muscles is evaluated with electrocautery-induced

contractions. Nonviable muscle mass should be debrided and hemostasis ensured.

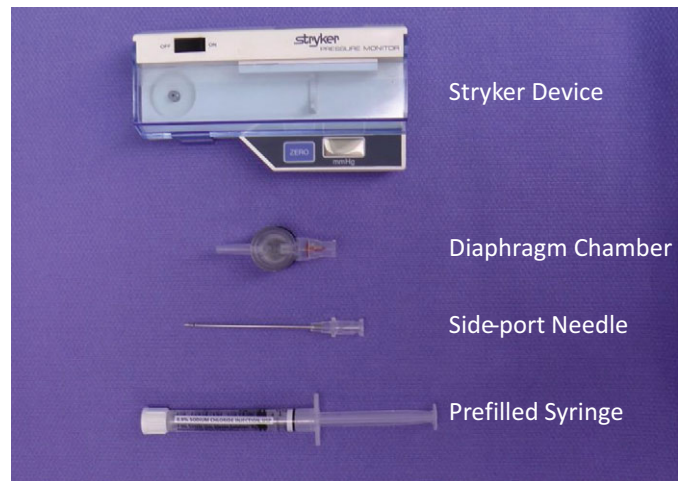
Special Instruments

- Stryker intracompartmental pressure measuring system with an 18 gauge side-ported needle.
- Alternatively, an arterial line transducer can be utilized with a standard 18 gauge needle.
- Basic orthopedic tray.
- Closure options: vessel loops and skin staples or negative pressure dressing system (VAC system).

Technique of Compartment Pressure Measurement

- Knowledge of the anatomy of the muscle compartments is critical. The pressure should be measured in all compartments individually. Adjacent compartments may have very different pressures.
- The most commonly used technique is with the handheld Stryker device. An alternative in the ICU is to set up a pressure transducer connected to a needle that may be inserted into the muscle compartment.
- Side-port needles are more accurate at measuring the compartment pressure than regular needles. This is due to soft tissue occluding the lumen of a standard needle.
- Steps for compartment pressure measurement with Stryker device:
 1. Connect the side-port needle to the diaphragm chamber, and the diaphragm to the prefilled syringe. Insert the assembled system into the device and snap the device closed. Turn unit on.
 2. Press the zero button and wait until the display shows 0.
 3. Insert the needle perpendicular to the skin and into the muscle.
 4. Slowly inject 0.3 mL into the compartment.
 5. Wait for a few seconds for the display to reach equilibrium, before reading pressure.

(a)



(b)

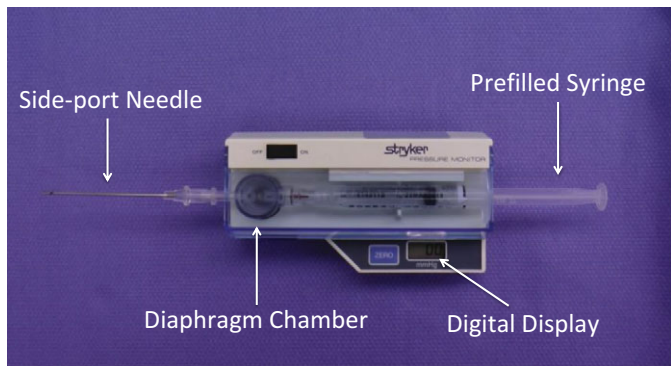


Figure 44.1 (a) Components of the Stryker device used for measurement of compartment pressures. (b) Assembled Stryker components placed in the device and ready for use.

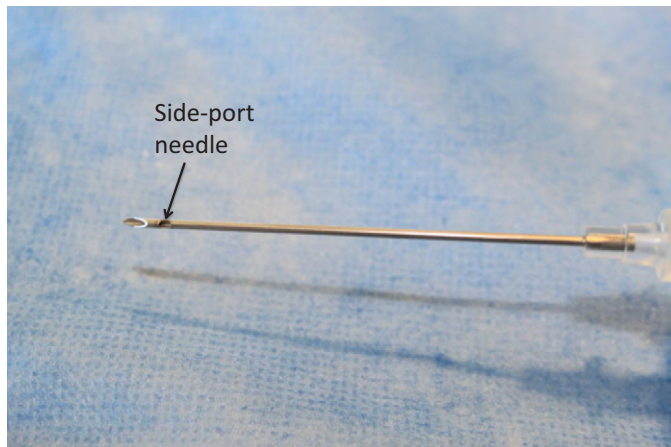


Figure 44.2 Side-port needles provide the most accurate measurement of compartment pressures. The location of the port prevents soft tissue from occluding the lumen.

Gluteal Compartment Fasciotomy

Patient Positioning

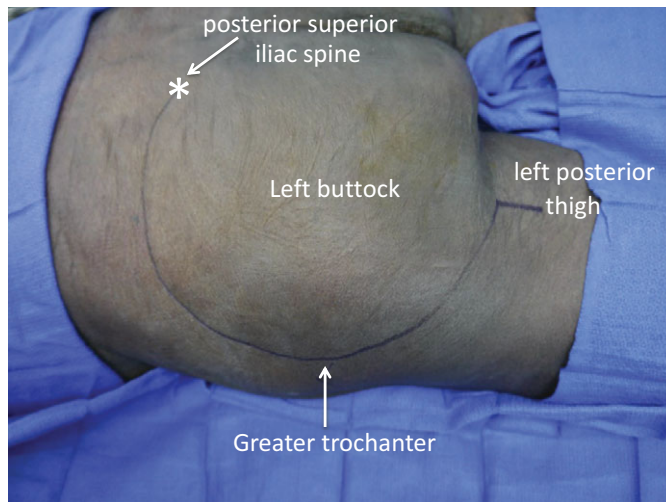
- Gluteal compartment fasciotomies are performed in the prone or lateral decubitus position.

Incisions

Gluteal compartment decompression can be achieved either through the traditional question mark incision or a midaxial longitudinal incision.

- The question mark incision starts at the posterior superior iliac spine, courses along the iliac crest, turns medially over the greater trochanter, and below the buttock it extends over the midline of the posterior upper thigh.
- The midaxial longitudinal incision begins just lateral to the posterior superior iliac spine and extends posterolaterally toward the lateral thigh. At the level of the trochanter, the incision turns inferiorly along the lateral aspect of the thigh to provide access to the fascia lata.

(a)



(b)

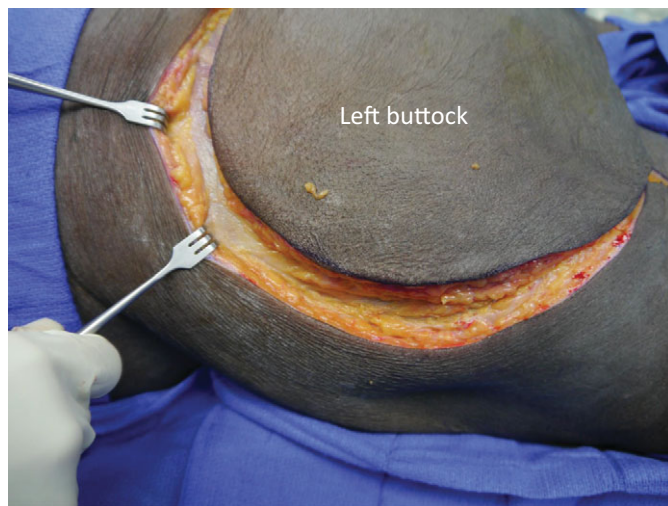
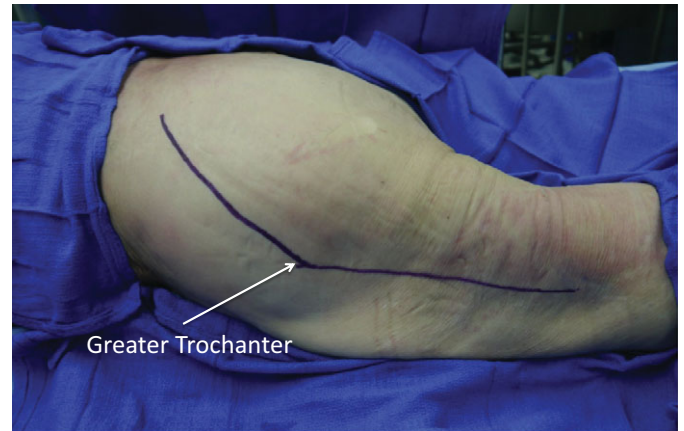


Figure 44.3 (a) Left buttock question mark incision for gluteal fasciotomy. The incision starts at the posterior superior iliac spine, courses along the iliac crest and turns medially over the greater trochanter. (b) The incision is extended down to the gluteal fascia.

(a)



(b)



Figure 44.4 (a) Left buttock mid axial longitudinal incision for gluteal fasciotomy (patient in prone position). The incision begins lateral to the posterior superior iliac spine and extends posterolaterally toward the lateral thigh; at the greater trochanter, the incision turns inferiorly along the lateral aspect of the thigh. (b) After making the skin incision, the dissection is continued until the fascia is identified.

Procedure

- The skin incision is carried through the subcutaneous tissue to the fascia. The gluteus maximus is directly encountered and the fascia is released.
- The muscle fibers of the gluteus maximus are split to access the underlying gluteus medius/minimus compartment.
- The inferolateral portion of the incision is used to release the tensor fascia lata.
- Following fasciotomy, the viability of the muscles is ensured with electrocautery-induced muscle contractions.
- Nonviable muscle mass is debrided and hemostasis is ensured. The wound is covered with negative pressure dressing system or wet-to-dry dressing.

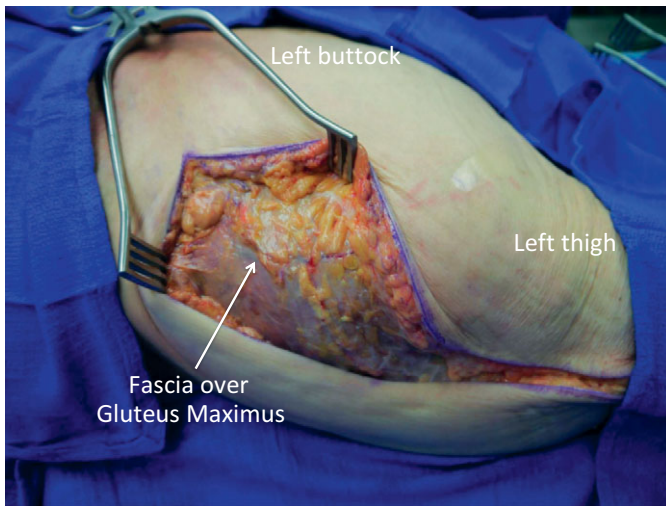


Figure 44.5 Fasciotomy of the left buttock (patient in prone position). The skin incision is carried through the subcutaneous tissue until the fascia of the gluteus maximus is identified.

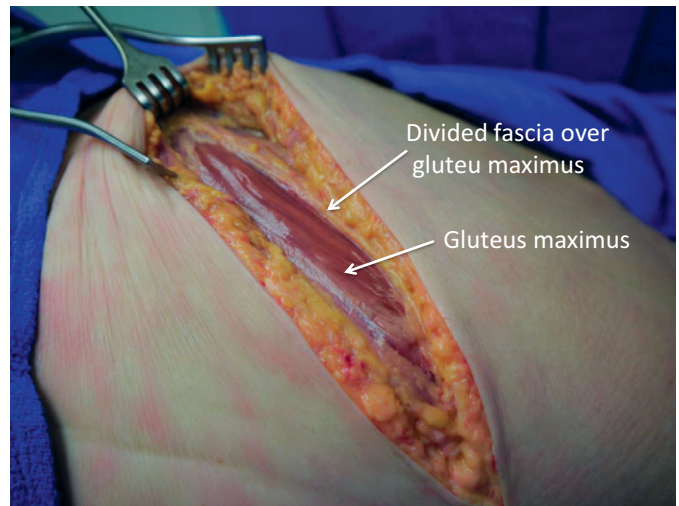


Figure 44.6 Once the fascia of the gluteus maximus is identified, it is incised to decompress the compartment.

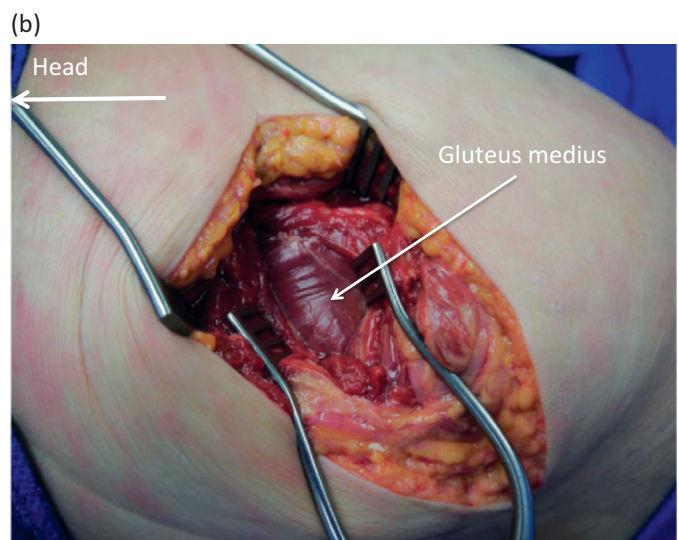
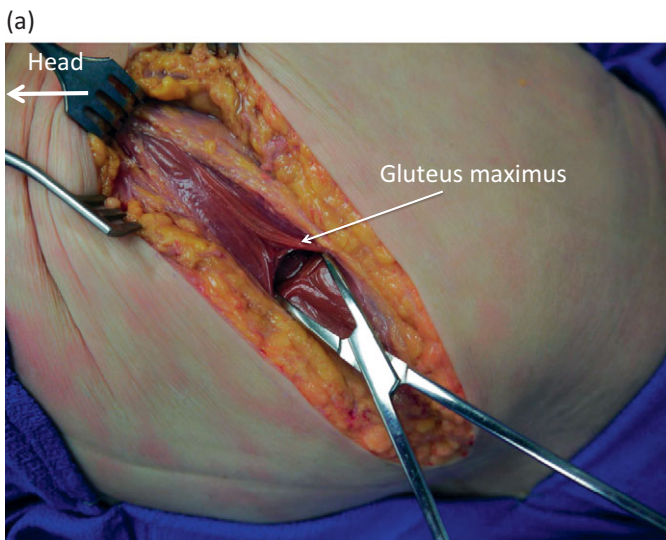


Figure 44.7 (a) After entering the compartment, the gluteus maximus is spread to access the deep compartment containing the gluteus medius and gluteus minimus. (b) Identification of the gluteus medius confirms entry into the deep compartment.

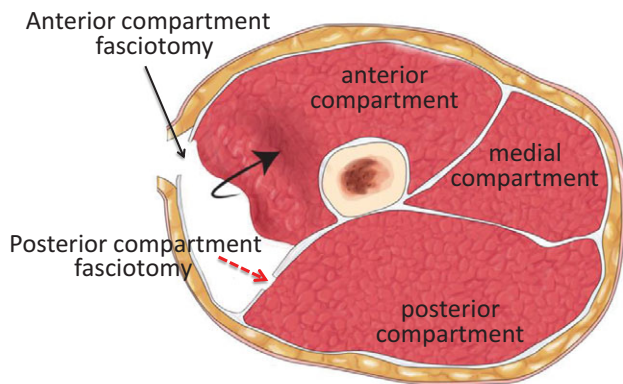


Figure 44.8 The thigh fasciotomy is performed through a lateral incision. The anterior and posterior compartments can both be decompressed through this single incision by retracting the vastus lateral (black curved arrow) and incising the intercompartmental septum (red arrow). Decompressing the anterior and posterior compartments will decrease pressure in the medial compartment. Medial compartment fasciotomy is rarely required.

Thigh Fasciotomy

Patient Positioning

- The patient is placed supine and the lower extremity prepped from the iliac crest to the foot.

Incisions

- In most cases, one lateral incision is performed to decompress both the anterior and posterior thigh compartments. The medial compartment rarely needs decompression, but if needed it can be accomplished through a medial incision.

Procedure

Lateral Incision

- The skin incision extends from just below the major trochanter to a few cm above the lateral femoral condyle. It is carried through the subcutaneous tissue and down to the fascia lata.
- The fascia lata is divided with a longitudinal incision to decompress the anterior compartment.

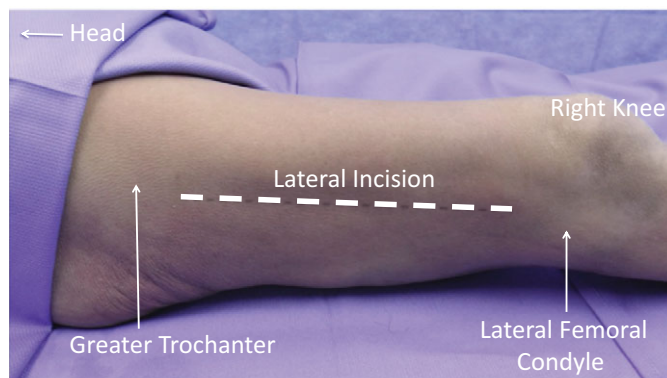


Figure 44.9 Right thigh fasciotomy. The lateral incision extends from just below the greater trochanter to a few centimeters above the lateral femoral condyle.

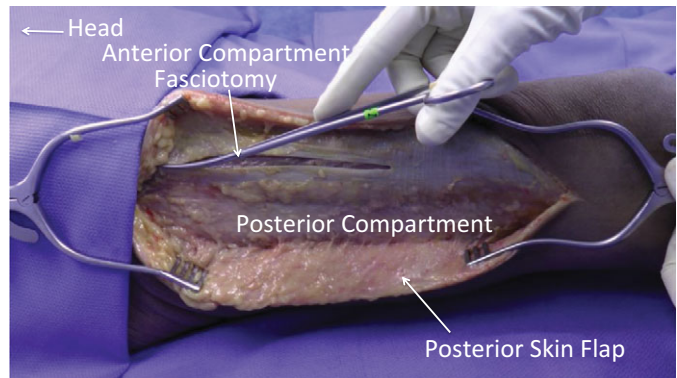


Figure 44.10 The incision is carried through the subcutaneous tissue until the fascia is identified. An anterior compartment fasciotomy is performed by dividing the fascia lata with a longitudinal incision.

- To decompress the posterior compartment, a posterior skin flap is mobilized and an incision is made in the fascia posterior to the intercompartmental septum.

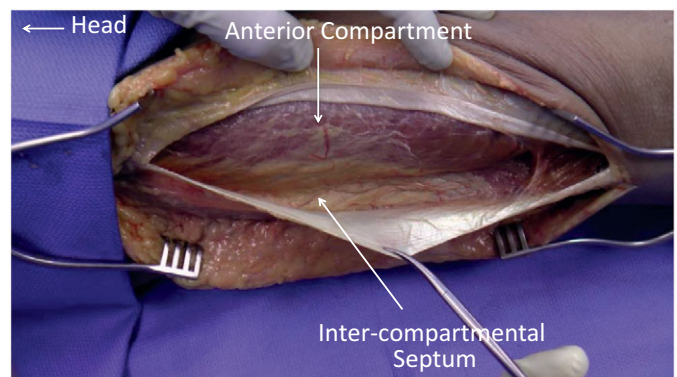


Figure 44.11 Fasciotomy right thigh. Retraction of the anterior compartment fascia will allow identification of the intercompartmental septum.

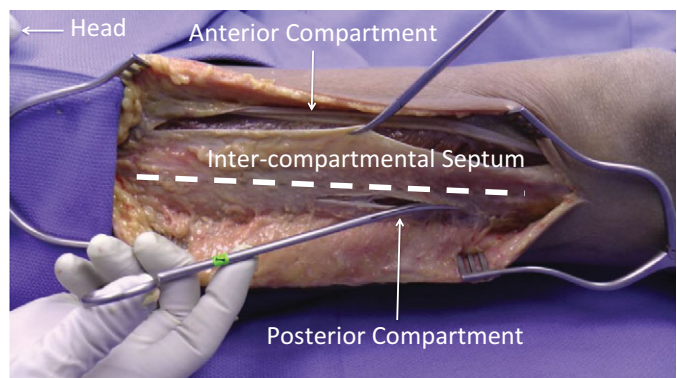


Figure 44.12 Fasciotomy right thigh. To decompress the posterior compartment, and an additional longitudinal incision can be made posterior to the intercompartmental septum.

- Alternatively, the intercompartmental septum can be accessed and incised by retracting the exposed vastus lateralis muscle superiorly and medially with large retractors.
- The lateral intermuscular septum between anterior and posterior compartments is incised for the length of the incision.

Medial Incision

- This incision is rarely needed because the medial muscle compartment is normally unaffected.
- By decompressing the anterior and posterior compartments, pressures in the medial compartment decrease as well. Measure the medial compartment pressures before proceeding to fasciotomy.
- In the average size male, a 20 to 25-cm medial incision is made, coursing adjacent to the greater saphenous vein, extending to a few cm above the medial femoral condyle.
- If decompression of the medial compartment is warranted, the saphenous vein should be preserved.

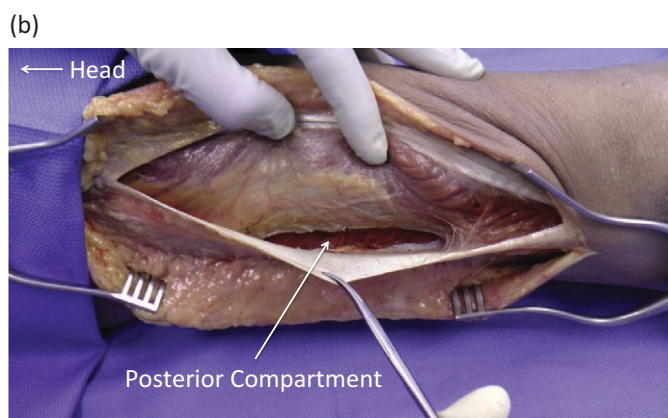
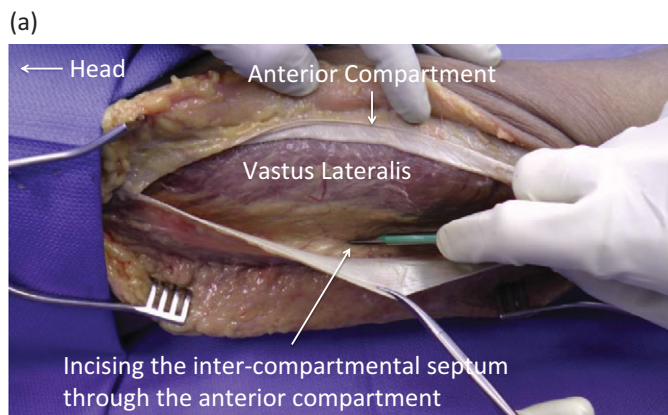


Figure 44.13 (a) Fasciotomy right thigh. Alternatively, the vastus lateralis can be retracted to expose the intercompartmental septum from within the anterior compartment, the septum is then divided sharply. (b) The septum should be divided for the length of the incision to ensure adequate decompression of the posterior compartment.

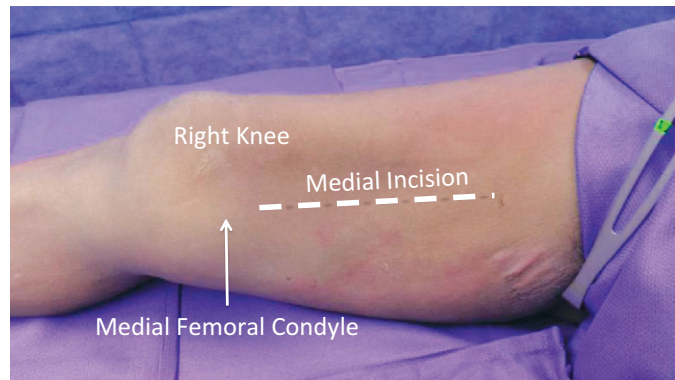


Figure 44.14 Right thigh fasciotomy. The medial incision follows the course of the saphenous vein and stops several centimeters above the medial femoral condyle.

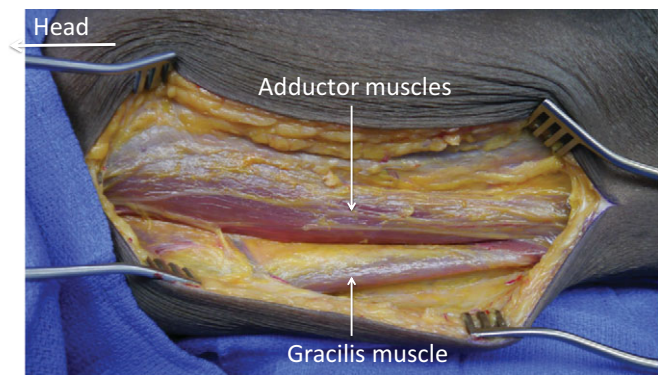


Figure 44.15 Fasciotomy right thigh. The fascia of the medial compartment is incised and the adductors identified.

Lower Leg Fasciotomy

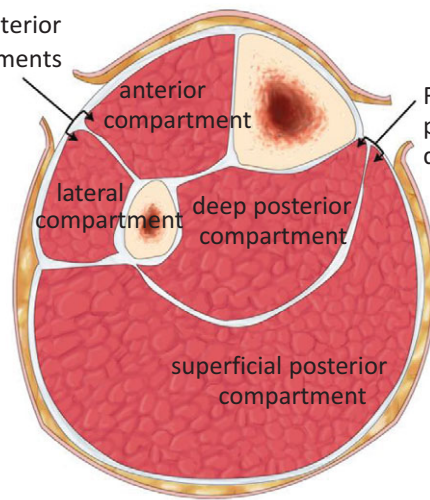
Patient Positioning

- The patient is placed supine and the leg prepped circumferentially. A sterile bump may be placed under the knee and calf to improve exposure.

Incisions

- The standard four-compartment fasciotomy of the lower leg is achieved through two incisions:
 - The lateral incision decompresses the anterior and lateral compartments.
 - The medial incision decompresses the superficial and deep posterior compartments.

Fasciotomy of the anterior and lateral compartments



Fasciotomy of the posterior superficial and deep compartments

Figure 44.16 Two incision, four compartment fasciotomy of the lower leg. The lateral incision releases the anterior and lateral compartments, the medial incision releases the deep and superficial posterior compartments.

Lateral Incision

- The lateral incision is performed midway between the fibula and the lateral tibia edge (about 2 fingerbreadths in front of the fibula), starting 2 fingerbreadths below the tibial tuberosity and extending to 2 fingerbreadths above the ankle. This incision is approximately over the septum separating the anterior from the lateral compartments. A line drawn from the head of the fibula to the lateral malleolus will serve as a useful landmark of the fibula.
- The skin incision should be carried through the subcutaneous tissue and down to the investing leg fascia. Skin flaps are raised to expose the fascia covering the anterior and lateral compartments of the leg, as well as the intramuscular septum between them.
- Identifying the septum is critical to ensure both compartments are released. Perforating vessels entering the septum may facilitate its identification. Another method to identify the septum is to make a transverse incision over the estimated site for confirmation. If making a transverse incision, attempt to identify the superficial peroneal nerve to avoid causing injury.
- The anterior compartment is decompressed through the fascia anterior to the intramuscular septum (about 2–3 fingerbreadths, usually directly under the skin incision). Decompression of the anterior compartment is achieved through a longitudinal fasciotomy with long, blunt-pointed scissors. The scissor tips are always turned away from the septum. The fasciotomy is directed towards the big toe distally and the patella proximally.

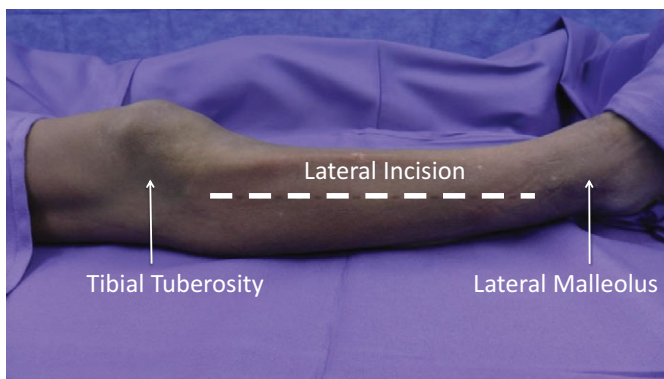


Figure 44.17 Fasciotomy of the right lower leg. The lateral incision is performed between the fibula and lateral edge of the tibia, extending from 2 fingerbreadths below the tibial tuberosity to a point 2 fingerbreadths above the lateral malleolus.

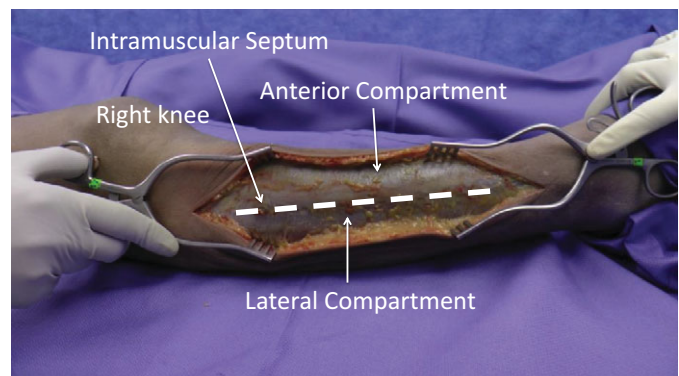


Figure 44.18 Lateral incision for right lower leg fasciotomy. The fascia overlying the anterior and lateral compartments is shown. Note the intramuscular septum.

- The lateral compartment is decompressed with a longitudinal incision posterior to the intramuscular septum. The fascia is incised with a direction towards the lateral malleolus distally and the head of the fibula proximally. Directing the distal fasciotomy towards the lateral malleolus is critical in order to avoid injury of the superficial peroneal nerve, as it pierces the septum in the distal third of the leg to take a subcutaneous course.

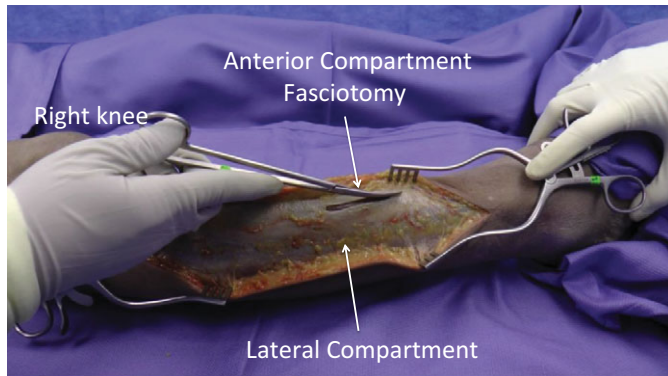


Figure 44.19 An anterior compartment fasciotomy is performed through a longitudinal incision with long blunt pointed scissors. The scissor tips should be pointed away from the septum to avoid injury to the superficial peroneal nerve.

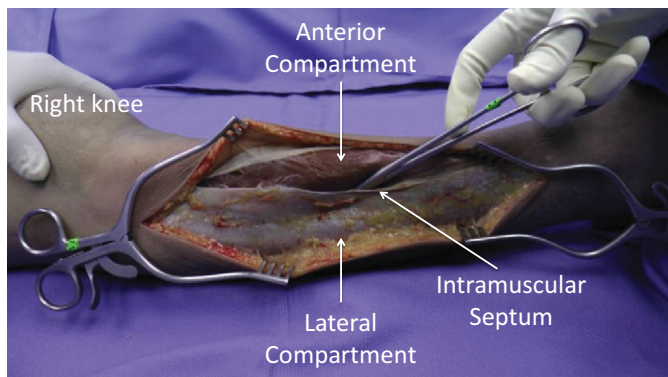
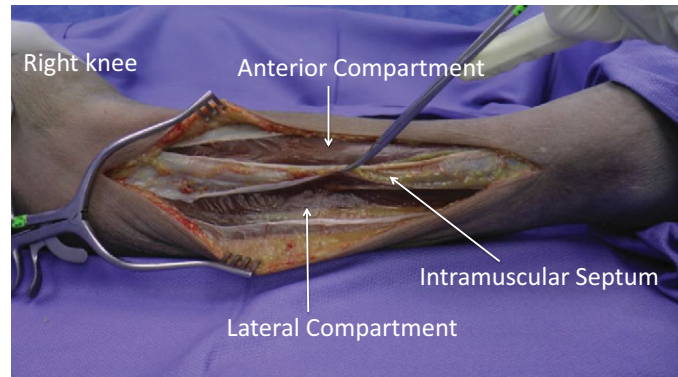


Figure 44.20 Identification of the septum is critical to ensure both compartments are released.

Medial Incision

- The medial incision is performed 2 fingerbreadths posterior to the medial edge of the tibia starting 2 fingerbreadths below the knee and extending 2 fingerbreadths above the ankle.

(a)



(b)

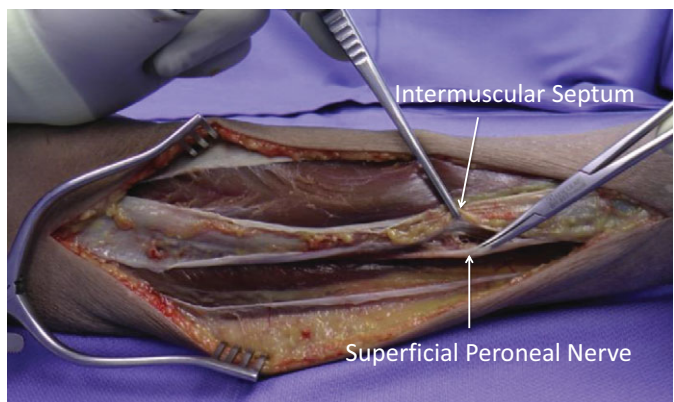


Figure 44.21 (a) The lateral compartment fasciotomy is performed with a longitudinal incision posterior the intramuscular septum. (b) During decompression of the lateral muscle compartment, care must be taken to avoid injury to the superficial peroneal nerve here, which pierces the septum in the distal third of the leg.

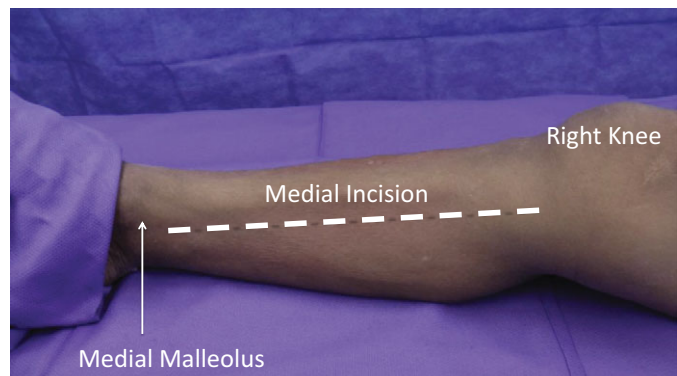


Figure 44.22 Fasciotomy of the right lower leg. The medial incision is performed 2 fingerbreadths posterior to the tibial edge.

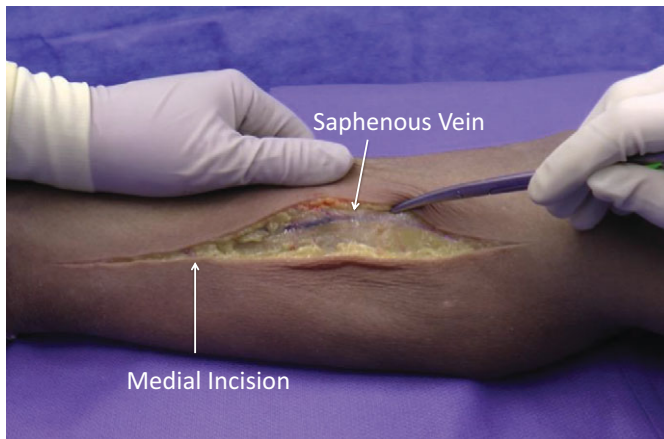


Figure 44.23 The saphenous vein should be identified and preserved while performing the medial incision for a lower leg fasciotomy.



Figure 44.24 The medial incision is carried through the subcutaneous tissue until the fascia overlying the superficial posterior compartment is identified.

- The skin incision is carried through the subcutaneous tissue and down to the investing fascia taking care to identify and preserve the great saphenous vein. Preserving the saphenous vein facilitates venous outflow from the leg.
- The superficial compartment is decompressed with a fascial incision, made about 2 fingerbreadths posterior and parallel to the incision for the deep compartment fasciotomy.

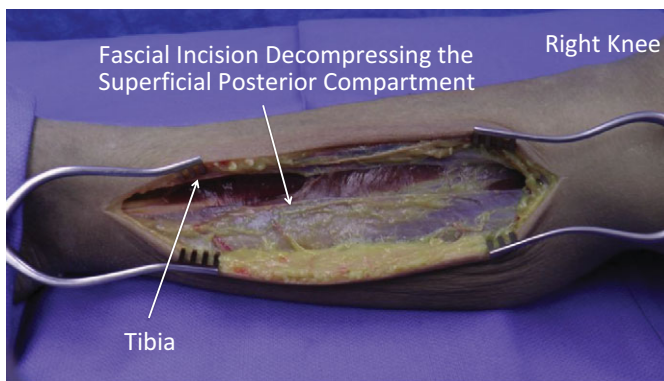
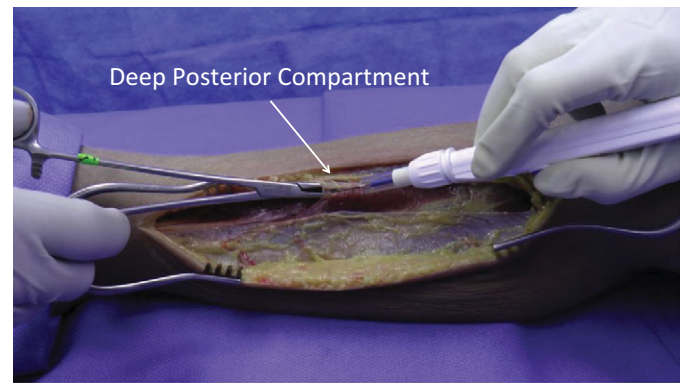


Figure 44.25 The superficial posterior compartment is decompressed with a longitudinal fascial incision 2 fingerbreadths posterior to the tibia.

(a)



(b)

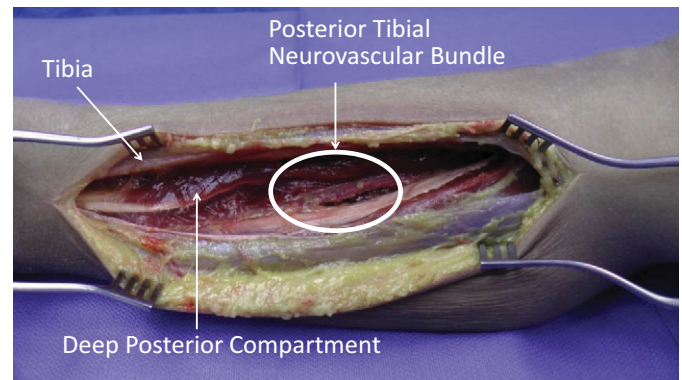


Figure 44.26 (a) The deep posterior compartment is decompressed through a fascial incision just behind the edge of the tibia. (b) Identification of the posterior tibial neurovascular bundle and the posterior surface of the tibia confirms the deep posterior compartment has been decompressed.

- The deep posterior compartment is decompressed with a fascial incision just behind the edge of the tibia. Identification of the posterior tibial neurovascular bundle, and the posterior surface of the bone, ensures that the deep compartment has been properly identified.

Foot Fasciotomy

The most common cause of foot compartment syndrome is crush injury.

Incisions

- The compartments of the foot are usually decompressed through three incisions: one medial incision and two dorsal incisions over the interosseous compartments.

Procedure

- The medial incision extends from a point below the medial malleolus to the metatarsophalangeal joint. This incision risks injury to the neurovascular bundle and some surgeons avoid it in favor of only two dorsal incisions.

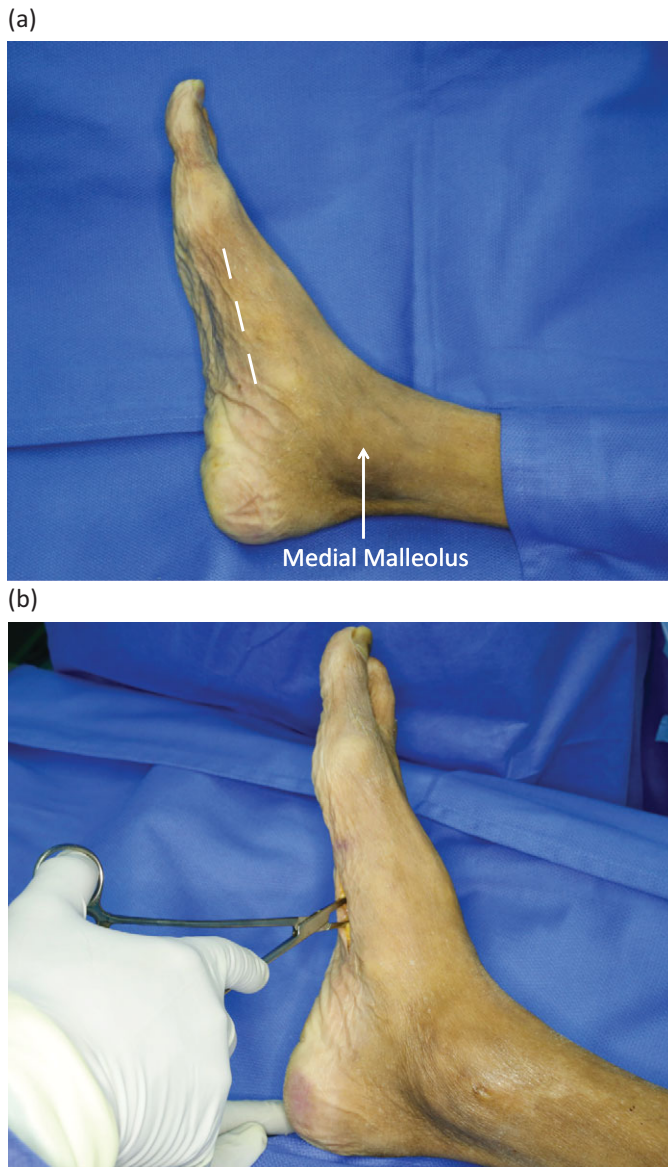


Figure 44.27 (a) Right foot fasciotomy. The medial incision extends from a point above the medial malleolus to the metatarsophalangeal joint. (b) Foot fasciotomy, decompression via a medial incision.

- The two dorsal incisions are placed over the second and fourth metatarsal shafts. Maintain a wide skin bridge to avoid necrosis. Skin flaps are raised to identify each of the interosseous compartments.

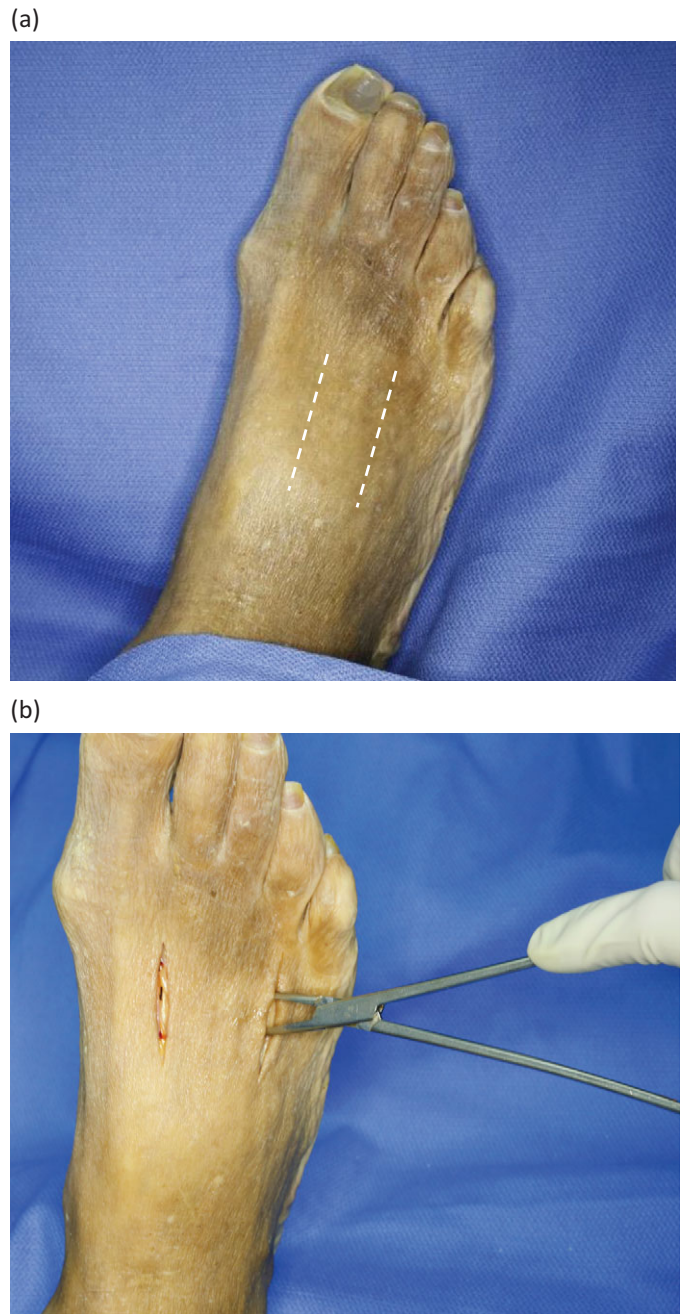


Figure 44.28 (a) Foot fasciotomy. Two dorsal incisions are placed over the second and fourth metatarsal shafts. (b) The interosseous compartments are identified and opened bluntly.

Fasciotomy Wound Management

- Negative pressure therapy dressing (VAC) is a useful modality to manage the fasciotomy sites. It prevents wound retraction, removes excessive soft tissue edema, and

facilitates delayed primary skin closure. However, its application in the presence of incomplete hemostasis may result in severe bleeding. It is advisable that this dressing is used after the second relook operation, when hemostasis is complete.

(a)



(b)



(c)



Figure 44.29 (a) Left lower leg fasciotomy with severe muscle swelling. VAC dressing will assist with removal of soft tissue edema and prevent further wound retraction. In these severe cases, VAC therapy is continued until adequate granulation tissue has formed to allow for split thickness skin grafting. Negative pressure therapy of a left buttock fasciotomy (b) and right lower extremity fasciotomies (c).



Figure 44.30 Vessel-loop shoelace wound closure over a fasciotomy wound.

- Vessel-loop shoelace wound closure is a useful technique to achieve delayed primary skin closure, and can be used at the index operation. Using skin staples, a red vessel loop is wound side to side along the length of the wound. Gentle traction is maintained to approximate the wound edges.
- If there is excessive swelling, or patient physiology requires a rapid exit from the operating room, simple wet-to-dry dressings can be applied to the wound.
- Once the swelling has subsided, the skin incisions can be closed primarily with interrupted mattress sutures. Do not close the underlying fascia.
- In some cases, the amount of swelling will not allow primary wound closure. These patients can be managed with VAC therapy until adequate granulation tissue forms within the wound. Split thickness skin grafting can then be performed.

Pitfalls

- Delayed diagnosis is the most common problem in the management of the compartment syndrome. High index of suspicion, serial clinical examinations, compartment pressure measurements, and serial CPK levels remain the cornerstone of early diagnosis and timely fasciotomy.
- The CPK levels may be normal in delayed recognition of the compartment syndrome and completely dead muscle.

- In suspected compartment syndrome the pressures should be measured in all compartments. The pressures may be normal in one compartment and abnormal in the adjacent one.
- Poor knowledge of the anatomy of the extremity muscle compartments is the most common cause of incomplete fasciotomy or iatrogenic damage to the neurovascular bundle. The superficial peroneal nerve is the most commonly injured nerve.
- The deep posterior compartment of the lower leg is the most commonly missed or incompletely released compartment. The easiest location to identify the deep posterior compartment is distal in the calf.
- Short skin incisions may result in an inadequate fasciotomy and progression of the ischemic neuromuscular damage, rhabdomyolysis, and renal failure.
- The skin incisions for a lower leg fasciotomy should not be too close to each other. A narrow skin bridge can lead to necrosis.
- Open fractures do not preclude compartment syndrome in the affected compartments.
- Swelling can continue to worsen, and initial low pressure measurements can lead to a false sense of security.



Figure 44.31 Inadequate lateral thigh fasciotomy. Note the significant muscle swelling. Short skin incisions can result in inadequate decompression of the compartment.

Orthopedic Damage Control

Eric Pagenkopf, Daniel Grabo, and Peter M. Hammer

General Principles

- The treatment goals of damage control surgery in orthopedics (DCO) include:
 - Give priority to other more severe, life-threatening associated injuries.
 - Improving vascular flow and subsequent tissue perfusion by reducing and realigning long bone fractures.
 - Temporary stabilization of long bone fractures, definitive fixation semi-electively, when the general condition of the patient improves.

Special Equipment

- Damage control surgery in orthopedics is centered around the placement of external fixators for long bone fractures and selected pelvic fractures. Placement of this hardware requires a set of specialized tools,

generally available in any facility that treats patients with orthopedic injuries.

- Instrument trays are manufactured by several different companies, but all will share similar components.
 - Pins – Placed into the cortex of the bone as the anchor point for the external fixator.
 - Pin Clamps – Secured around two pins, providing the bridge between the pins and the connecting rods. Each pin clamp can be affixed with two posts (straight, 30°, 90°) and can be rotated into 12 different positions, thus giving maximal flexibility to the structure of the external fixator.
 - Pin to Rod Coupler – Can connect a pin to a connecting rod, when a pin clamp is not used.
 - Rod to Rod Coupler – Can connect a connecting rod to a post or another connecting rod.
 - Drill – Can be either pneumatic-driven or battery powered.

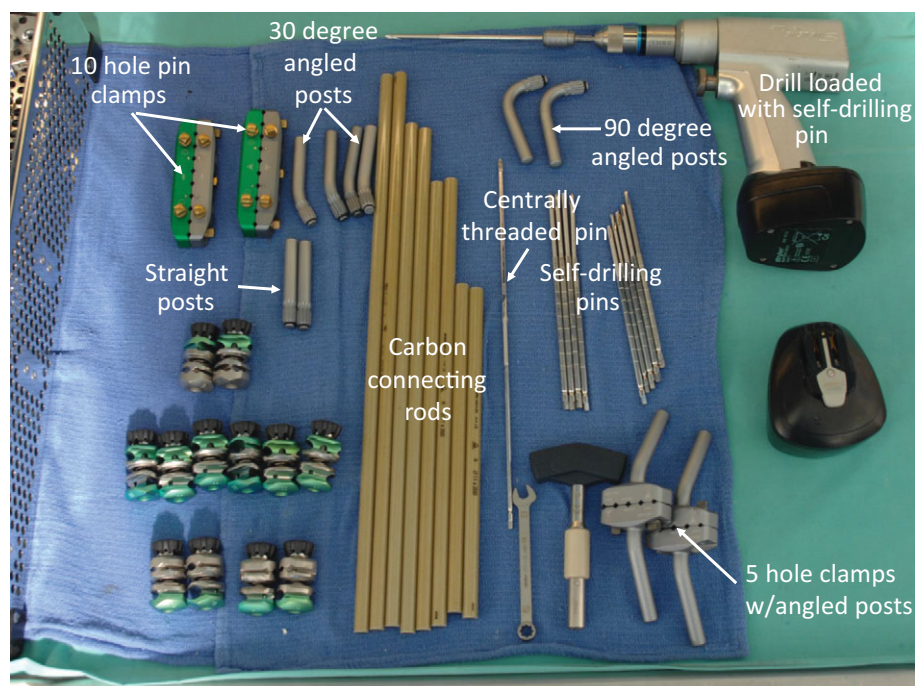
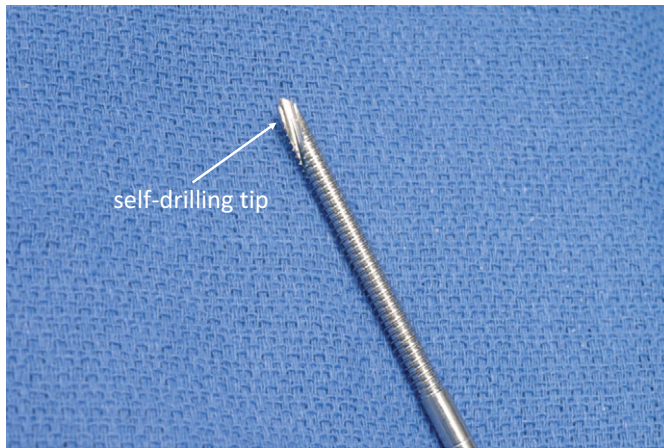


Figure 45.1 A representative sample of equipment found in a standard external fixator set.

- For pin selection, the choice is between a blunt and a self-drilling pin. Blunt pins require pre-drilling of holes in the cortex. Self-drilling pins can be mounted directly onto the drill and drilled into place.
- Another screw that may be necessary is a centrally threaded pin. This long pin has a self-drilling tip, but the threads are located in the middle of the pin, not at the end. This pin is placed across the calcaneus, when an ankle-bridging external fixator must be placed.

(a)



(b)

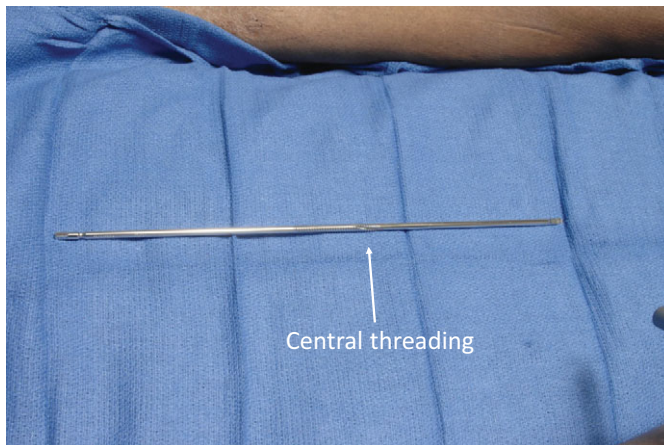


Figure 45.2 (a) A self-drilling pin. Pre-drilling the bone prior to placement is not required. (b) A central-threaded pin used when placing an ankle-bridging external fixator. The pin is placed through the calcaneus, with the central threads engaging the cortex on both sides.

Positioning of Patient

Placement of external fixators on the lower extremities requires the patient to be in the supine position with the legs in a neutral position.

Management of Specific Fractures

Mid-Shaft Tibia Fracture

- After the decision has been made to stabilize a tibial fracture with an external fixator, the locations of the anchoring pins must be decided. Two pins should be placed on each side of a fracture site. One is inadequate to provide stability.
 - When choosing a location, the pin closest to the fracture site must be greater than 2 cm away. Pin placement too close to the fracture could prevent adequate stabilization.
 - Care must be taken to avoid placing a pin in the metaphysis or intra-articular.
 - If the fracture is very proximal or distal and there isn't adequate tibial shaft to place pins, an articular-spanning fixator must be placed (see below). The safest area to place pins into the tibia is anywhere between the anterior tibial ridge to 60° medially.

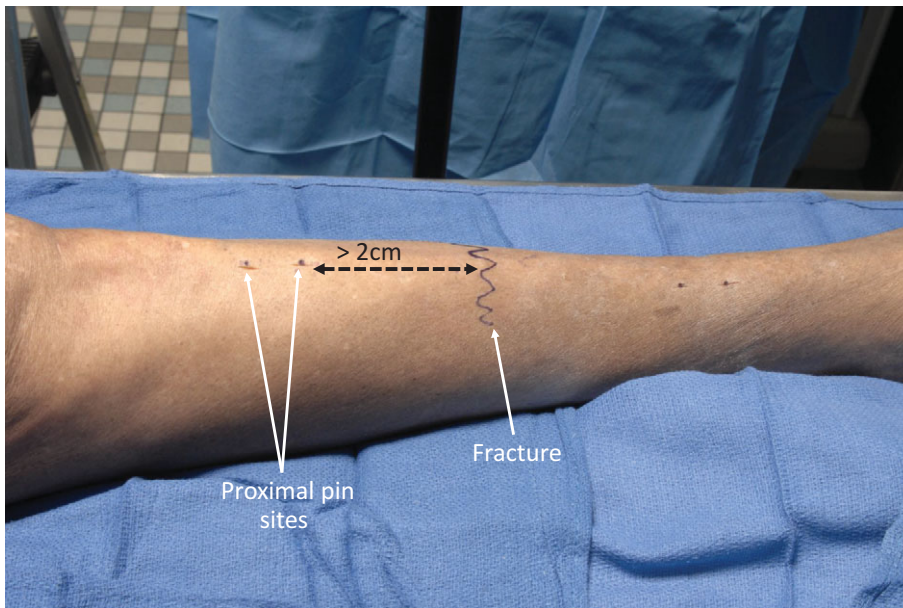


Figure 45.3 Pin site placement in relation to the fracture. Safe placement is along the anterior aspect of the tibia, with pins placed >2 cm from fracture. Avoid the metaphysis.

- Make a 4 mm incision over the pin sites with a scalpel and carry down through the periosteum. With the self-drilling pin loaded on the drill, place the tip of the pin directly on the cortex. Apply partial power to the drill until the pin adequately engages. Then, increase power on the drill. After the tip of the pin passes through the first layer of cortex and into the medulla, there will be decreased resistance. As the tip engages to far cortex, the resistance will increase again. Be sure to allow for several more revolutions of the pin to be sure that there is secure bicortical purchase. Without bicortical purchase, the pins can come loose and the external fixator can fail to adequately hold reduction.
- Repeat the above process with the second pin. When judging how far to place the second pin from the first, use a 5- or 10-hole pin clamp as your guide. You should place the pins as far apart as possible, but still be able to fit into one clamp. The second pin should be placed parallel to the first.
- Repeat the above process with the distal pins.

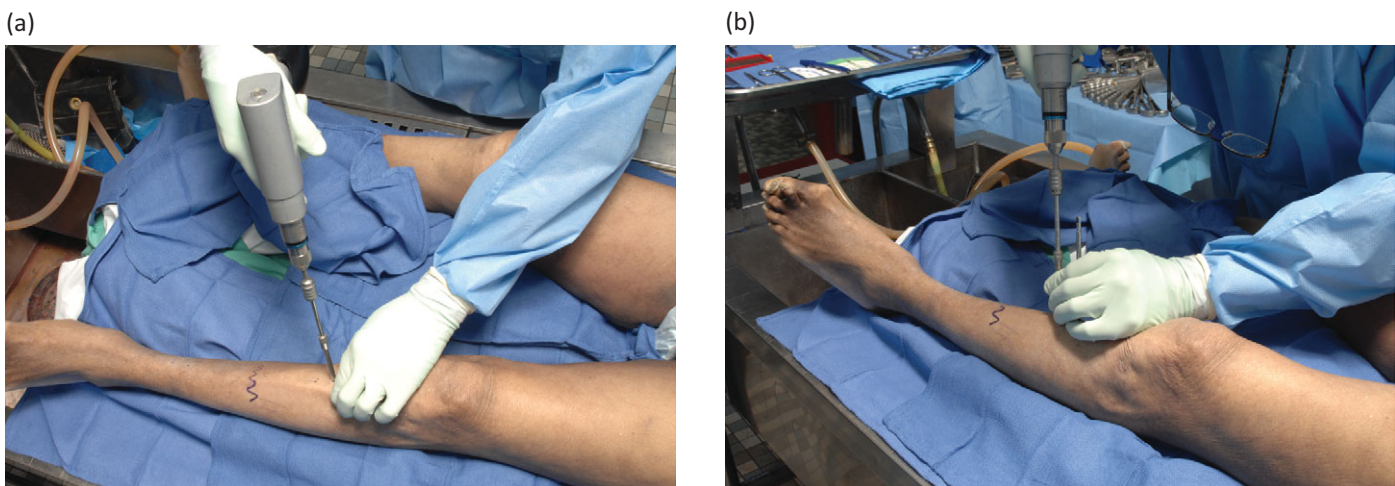


Figure 45.4 (a) Drilling the pin into the tibia. It is important that the pin has a bicortical purchase for maximum stability. (b) Placement of the second pin. The pin should be placed roughly parallel to the first, with the largest gap allowed between pins to be placed within the pin clamp. (c) Repeat the previous step distal to the fracture site.

(c)



Figure 45.4 (cont.)

- Pin clamps must now be secured around the pins. The clamp should be placed roughly 1.5–2 cm from the skin, or 2 fingerbreadths.
- Tighten all fasteners with full hand torque, while applying counter-torque to prevent damage to the fixator hardware.

(a)



Figure 45.5 (a) Pin clamp placement. The five-hole pin clamps used here have 30° angled posts. Pin clamps allow for placement of different angled posts, pointing in any direction. The clamp should be placed approximately 1.5–2 cm from the skin/soft tissue. Two fingerbreadths is a good way to judge adequate placement. (b) Tightening all bolts with full torque, while applying counter-torque to prevent damage to the fixator hardware.

(b)



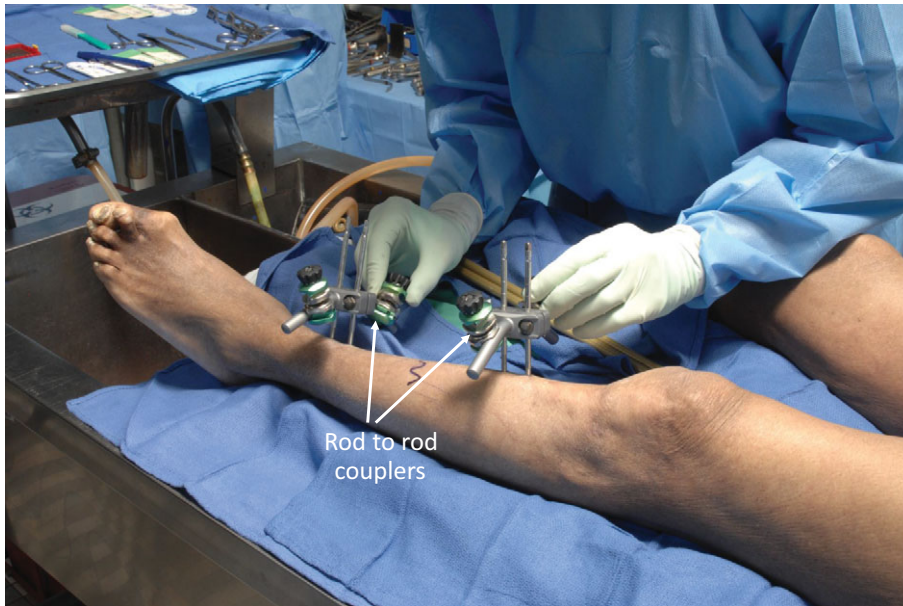


Figure 45.6 Applying the couplers to the angled posts. They should be placed near mid-post to provide better stability.

- Attach Rod to Rod couplers to the posts, one on each side of the clamp. Optimal location is mid-post.
- At least two connecting rods should be placed parallel to the long bone, preferably one medial and one lateral. When

placing the connecting rods, a second person should pull the limb out to length and reduce the fracture. With the fracture reduced, the Rod to Rod couplers should be tightened, thus securing the limb in place.

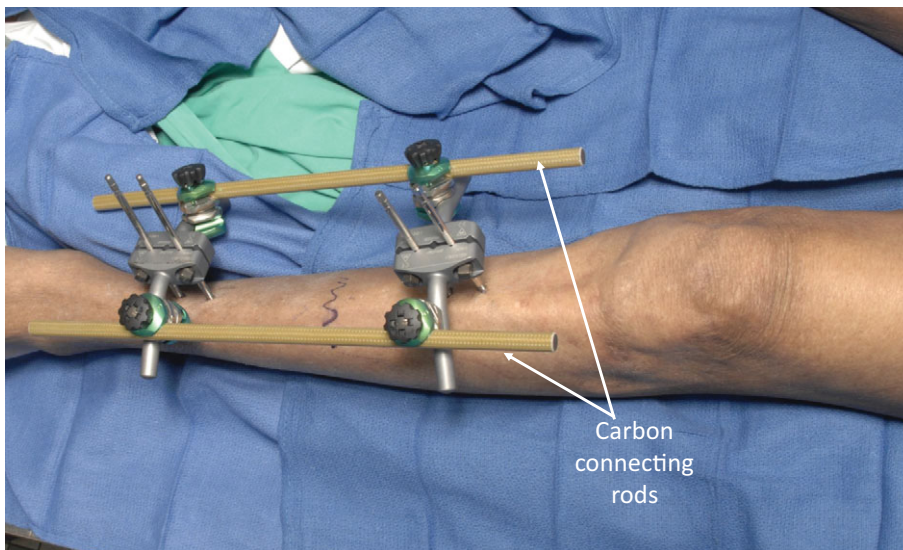


Figure 45.7 Final hardware apparatus after insertion of the connecting rods and tightening of all fasteners.

Distal Tibia and Fibula Fracture/Ankle Instability

- In the event that a tibial fracture is too distal to allow for pin placement above the metaphysis, an ankle-bridging external fixator must be placed. The proximal pins are placed in the tibia as described above. For the distal pin, a calcaneal pin must be placed. An incision is made over the medial aspect of the center of the calcaneus.
- Using a centrally threaded pin, drill the pin medial to lateral. Care must be taken to avoid the posterior tibial artery. This should be inserted until the threads have a bicortical purchase on both sides of the calcaneus.

(a)



(b)

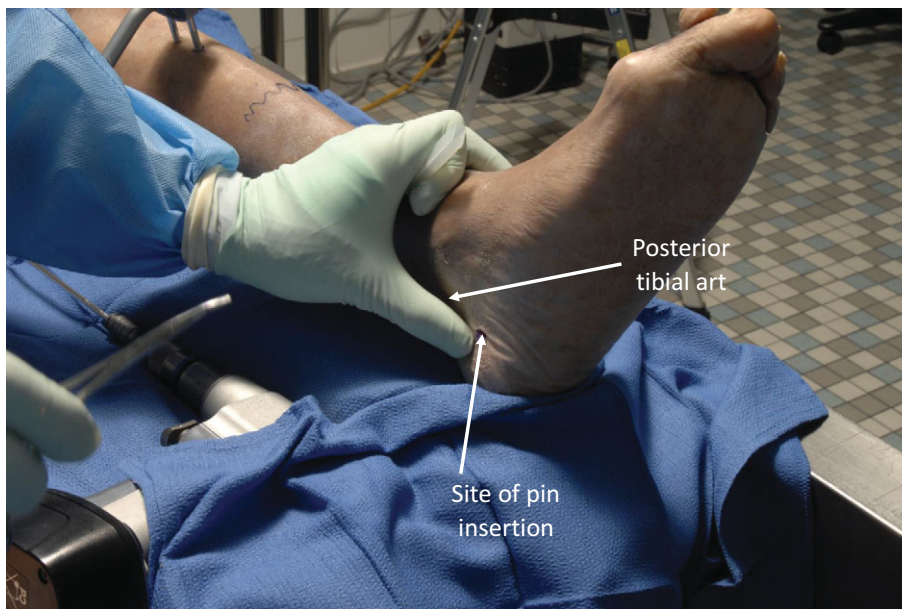


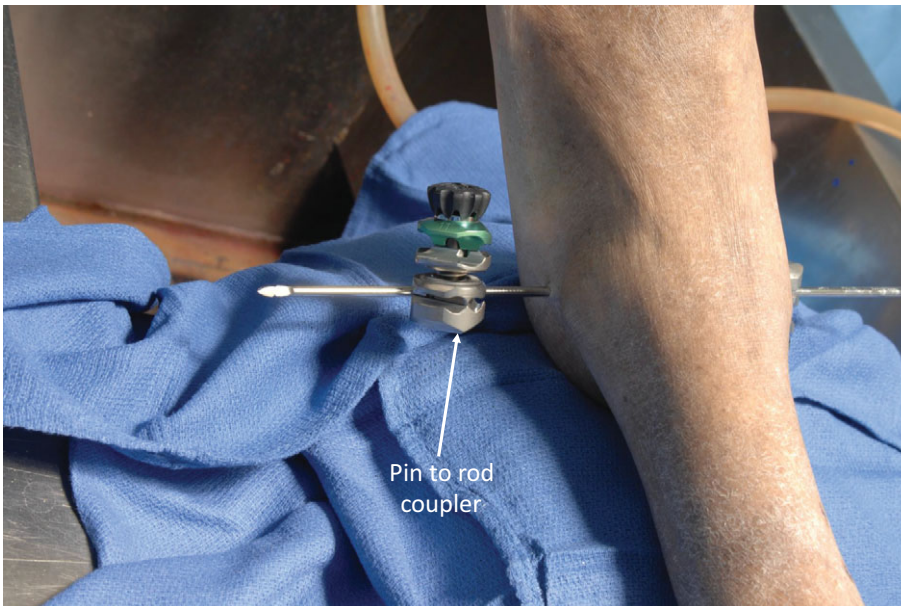
Figure 45.8 (a) Incision for the distal pin is placed over the medial calcaneus. (b) Using a centrally threaded self-drilling pin, the distal fixation pin is safely placed from a medial approach, taking care to avoid the posterior tibial artery.

(a)



Figure 45.9 (a) The centrally threaded pin in place, with the threads engaged in the cortex on both sides of the calcaneus. (b) For the single pin, a pin to rod coupler is used.

(b)



- Since a single pin is used, a Pin to Rod coupler must be used. One should be placed on each side of the foot.
- The connecting rods should be placed in the same fashion as for a mid-shaft tibia fracture.
- If there is concern that the patient could develop skin breakdown over the ankle, a posterior semi-circular connecting rod could be placed.

(a)

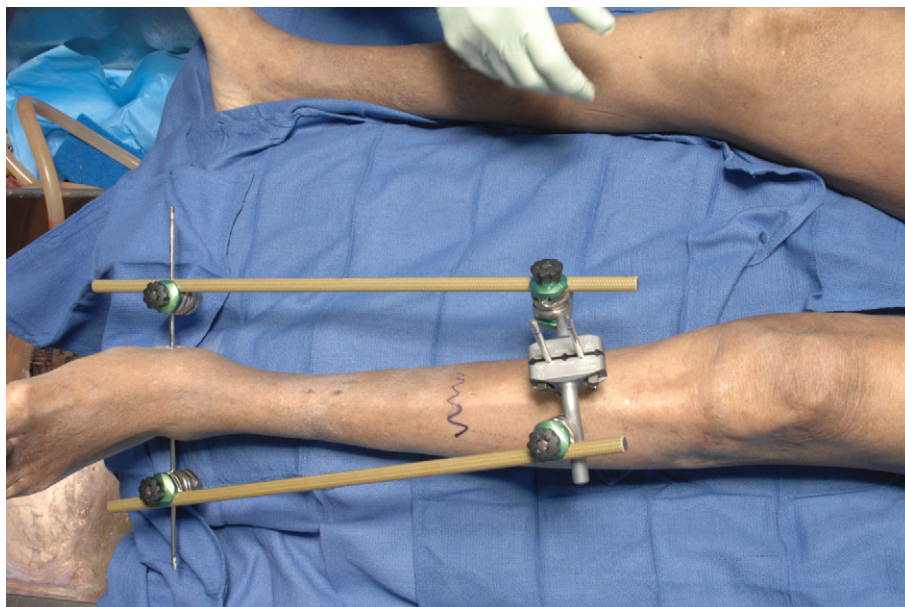
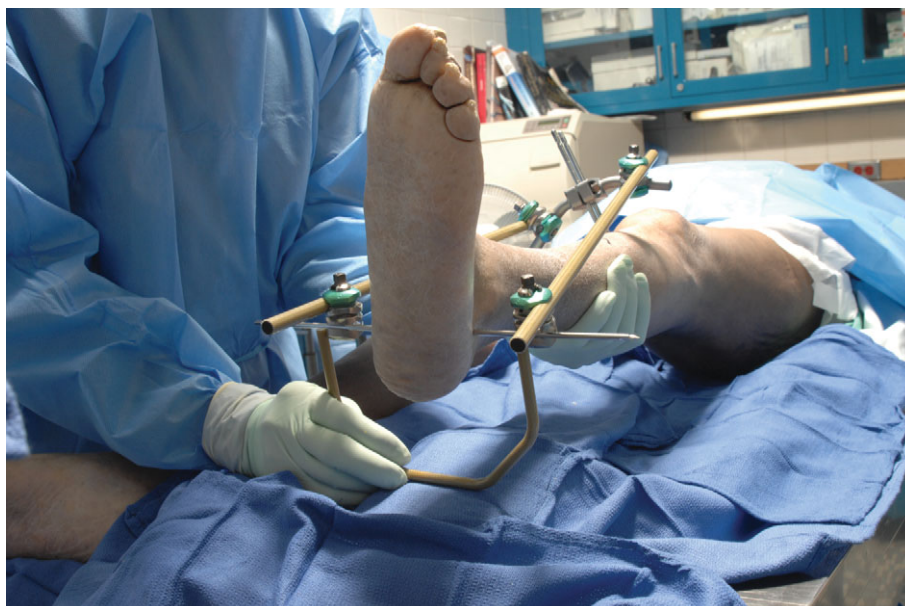


Figure 45.10 (a) The distal fixation hardware in place with bilateral connecting rods. (b) A semicircular rod can be placed posteriorly to elevate the ankle off of the bed, thus preventing a potential pressure sore.

(b)



Mid-Shaft Femur Fractures

- When stabilizing a mid-shaft femur fracture, the same principles apply as to a tibial fracture. Pins should be

placed no closer to the fracture than 2 cm. The safest approach to the femur is laterally.

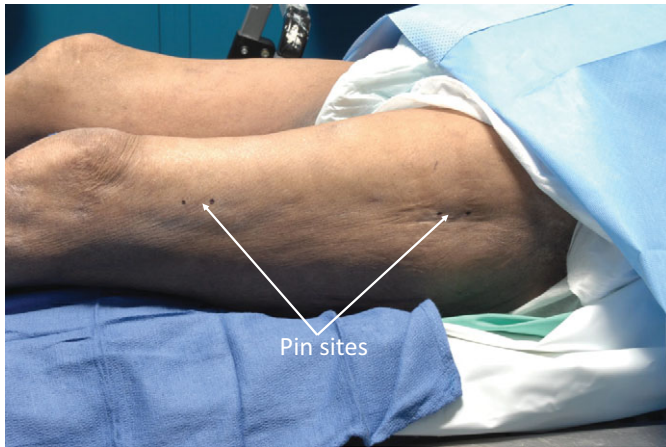


Figure 45.11 Pin site selection for a mid-shaft femur fracture. Safe placement is from the lateral approach.

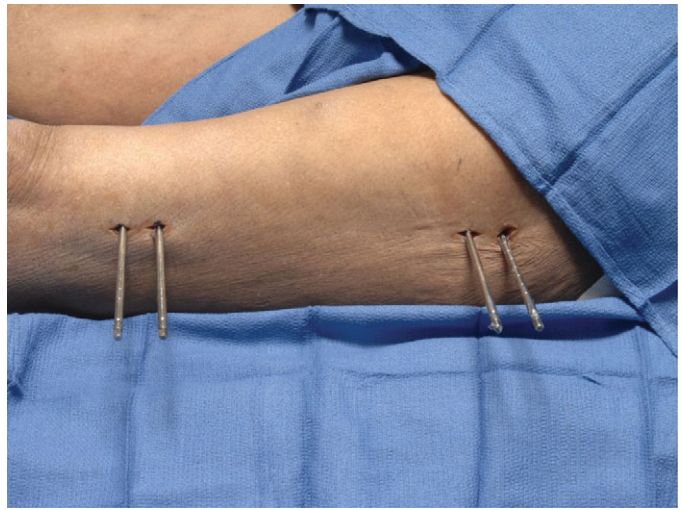


Figure 45.12 Fixation pins in place in the femur.

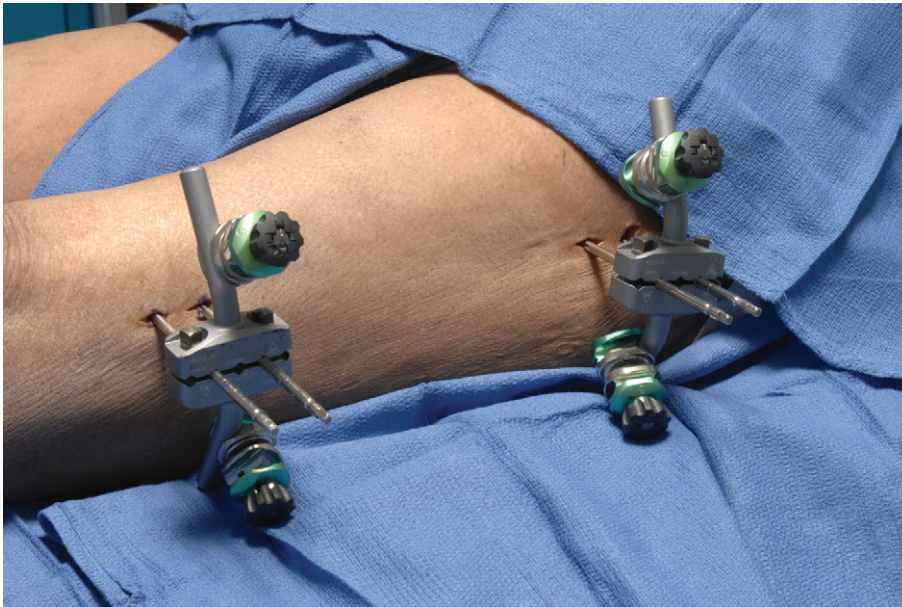
- Pin clamp selection is the same as for the tibia. Be sure that they are 2 fingerbreadths away from the skin.
- Angled or straight posts can be used.

(a)



Figure 45.13 (a) Pin clamp with angled posts being placed 2 fingerbreadths from the skin. (b) Both pin clamps in place, with attached post to rod couplers. (c) The final femur external fixation hardware, with connecting rods in place.

(b)



(c)

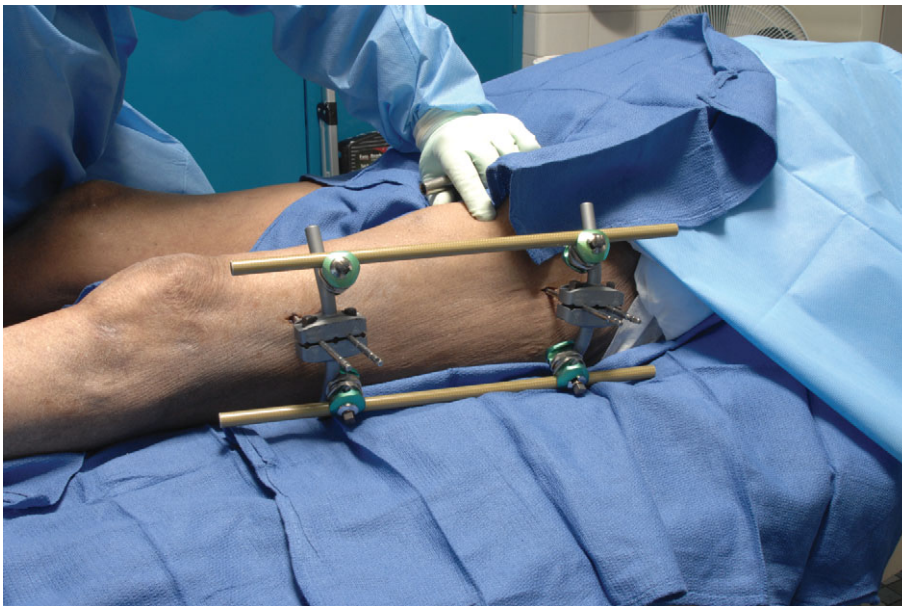


Figure 45.13 (cont.)

- As with the tibia, the femur should be pulled to length before completely tightening the fasteners on the connecting rods.

Distal Femur/Proximal Tibia

- For fractures involving the distal femur or proximal tibia that preclude safe pin placement outside of the knee joint, a

knee-spanning fixator may be required. Pin site selection criteria on the femur are the same as for a mid-shaft femur fracture. Since the entire weight of the lower leg will be resting on the knee-spanning apparatus, further-spaced pin placement in the tibia may be necessary.

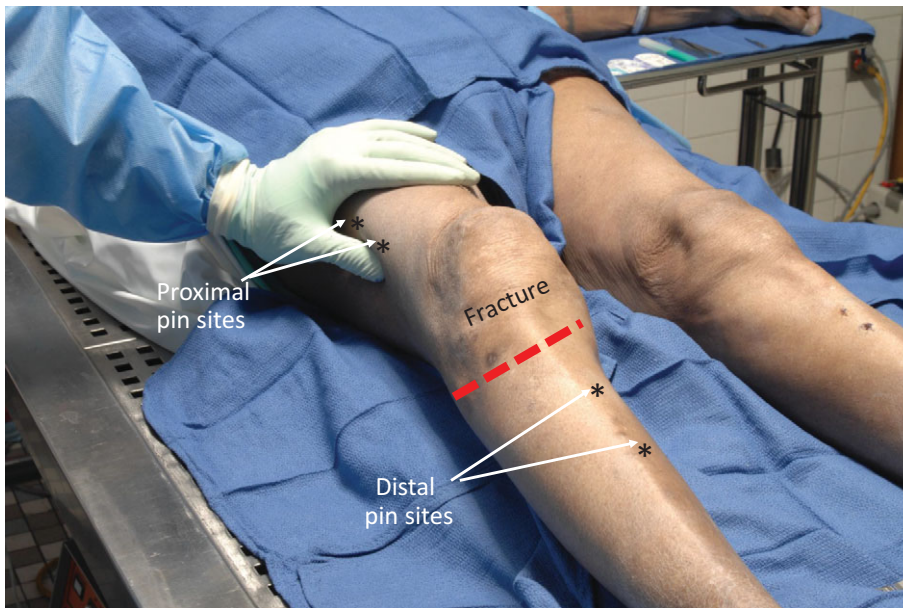


Figure 45.14 Proximal and distal pin sites for treatment of distal femur/proximal tibia fractures. For the proximal pins, the lateral approach is safest.

(a)



Figure 45.15 (a) Proximal pins in place. (b) Distal pin placement into the tibia. As with a tibia fracture, the safe pin approach is along the anterior surface. (c) After the distal pins are in place. Since the length of the external fixator is significantly longer when bridging the knee, placing the distal pins further apart will provide an increase in stability.

(b)



(c)



Figure 45.15 (cont.)

(a)



Figure 45.16 (a) Pin to rod couplers in place. Because the pins were placed far apart to increase stability, pin clamps will likely not be long enough to use. Couplers are necessary for connecting hardware. (b) The knee-spanning external fixator in place. Only one spanning rod is present in the picture. If the surgeon feels that there isn't enough stability, a second spanning bar could be placed.

(b)



"Floating Knee"

- A special case could arise, where there is both a distal femur fracture and proximal tibia fracture. A knee-spanning external fixator would provide stability to the lower leg, but the bony structures of the knee joint would still be unstable. This would be an instance where a long-

leg splint would need to be placed, in addition to the knee-spanning external fixator.

Pin Care

- External fixator pin sites can be a focus of infection. The pin sites should be cleaned daily with chlorhexidine gluconate and dressed with iodine-soaked gauze.

Tips and Pitfalls

- Not every patient who suffers a long bone fracture will require a damage control intervention. Knowing when to apply the principles of early definitive fixation versus DCO requires clinical knowledge and skill in managing these types of fractures. Communication between all members of the team is critical to achieving optimal outcomes in these multisystem injuries.
- As with any reduction of a comminuted fracture, after application of external fixation hardware, a post-reduction neurovascular check must be performed and documented in the record.
- Pin placement in relation to the fracture site is very important. Pins placed too close to the site will not provide adequate stability to reduce and stabilize long bone fractures. When placing the two pins, try to place the pins far apart, but still able to fit into the pin clamp.
- When placing an ankle bridging external fixator, attention must be paid to anatomy to avoid neurovascular structures, such as the posterior tibial artery.
- All screws and bolts must be tightened to full torque to prevent equipment slippage and loss of fracture reduction. Counter-torque must be held on the hardware to prevent damage during tightening.

Skin Graft Technique

Justin Gillenwater and Warren Garner

General Principles

- Deep partial or full thickness skin wounds, with an underlying vascularized bed, may be closed by autologous skin grafting, especially if healing by contracture would lead to prolonged healing time or functional or aesthetic deformity. Split thickness skin grafts (STSGs) are used most often for large wounds. Thin (0.06–0.010 in.), intermediate (0.010–0.013 in.), and thick (>0.014 in.) split thickness grafts can be harvested. Thinner grafts survive more reliably on a less vascular bed and have faster donor site healing; however, thinner grafts contract more than thicker grafts and the esthetic results are inferior. Most STSGs are of intermediate thickness, 0.012 in. Thinner grafts (0.010) should be considered in children and the elderly due to their thinner dermis.
- STSG donor sites heal by re-epithelialization with proper wound care. The lateral thigh or back are the most common donor sites, although STSGs may be harvested from nearly any uninjured anatomic area, including buttocks, abdomen, scrotum, and scalp.
- Meshed STSGs can be expanded and require less donor site than sheet grafts, but contract more and the esthetic results are not as good. Sheet grafts are used in children or in areas where contracture is unacceptable.
- Full thickness skin grafts have little role in acute wound closure. These are reserved for delayed reconstruction of critical areas, such as the hands and face.
- Meticulous technique is important for graft success, and includes hemostasis, placement of dressings, and adequate postoperative immobilization.

Special Equipment

- An electrical or air-powered dermatome with various width guards and a disposable blade are needed for graft harvest.

- Mineral oil or other lubricant is used on the graft donor site prior to harvest.
- Dilute epinephrine solution may be placed on the donor site afterwards to limit blood loss.
- For graft meshing, a graft mesher and compatible skin graft carrier are required.
- Material for the skin graft bolster should be available, and if negative pressure wound therapy (NPWT) is to be used, the machine should be requested beforehand.



Figure 46.1 Zimmer air-powered dermatome with various width guards.

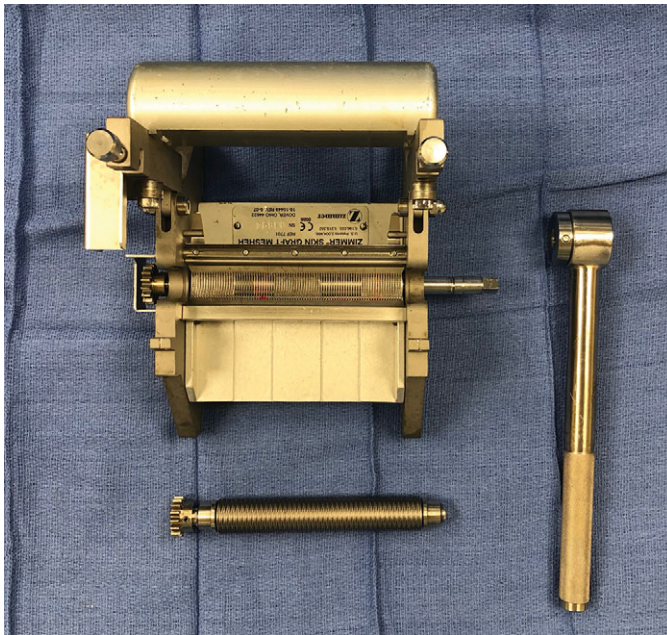


Figure 46.2 Skin graft mesher with wheels capable of meshing in different ratios, handle, and carrier.

Preoperative Considerations

- Comorbid medical conditions that affect wound healing should be optimized prior to skin grafting.
- Nutritional demands should be assessed and addressed before grafting, since many patients with large wounds are hypermetabolic. Serum albumin levels on admission are reflective of chronic nutritional status, while prealbumin levels can be monitored for current needs. Enteral feeds are preferred, and nasogastric tube feeding may be required if the patient is unable to support their own caloric requirements. Parenteral nutrition can be considered in a patient not tolerating enteral feeds.
- Chronic or infected wounds require serial debridement or staging to reduce the bacterial burden of the wound. Preoperative quantitative tissue cultures may be obtained to verify low bacterial burden. Bacterial loads greater than 10^5 are associated with higher rates of graft failure. Presence of specific organisms such as *Staphylococcus* or *Pseudomonas* species are not contraindications to grafting, if quantitative counts are low and the wound is not clinically infected.

Surgical Procedure

Excision/Wound Bed Prep

- The wound is surgically excised or debrided to healthy vascularized tissue. This reduces bacterial presence in the wound. All necrotic or questionably vascular tissue is removed from the wound. If, after debridement, the wound still has questionable vascularity or residual infection after excision, local wound care can be utilized or serial debridement performed until an adequate base is achieved. If critical or avascular structures (e.g., large vessels, nerves, tendons, or joints) are exposed during debridement, alternative methods of closure should be considered.

(a)



(b)

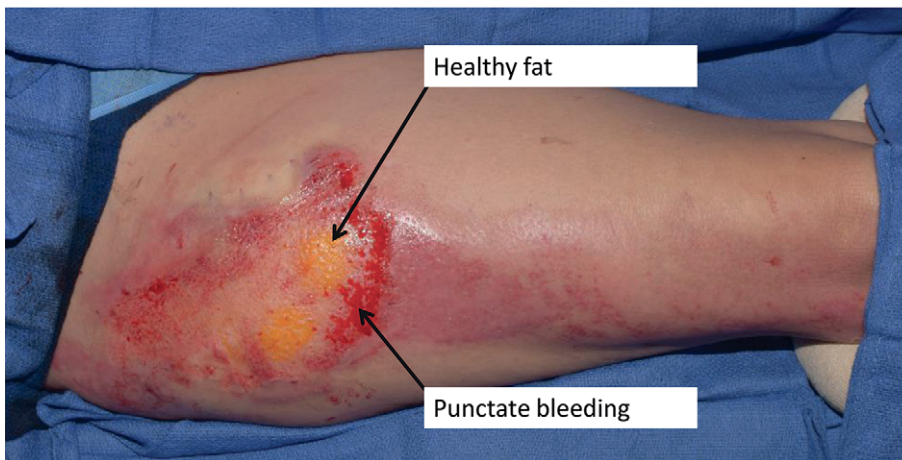


Figure 46.3 (a) Right Leg full thickness burn wound requiring excision and skin grafting. (b) Injection with dilute epinephrine solution. (c) Preparing the wound bed for grafting by excision of nonviable, burned tissue. (d) Right Leg full thickness burn wound after excision to healthy, graftable wound bed.

(c)



(d)

**Figure 46.3** (cont.)

Measure and document final dimensions and anatomical location of the wound after preparation.

Hemostasis

- After wound bed preparation, meticulous hemostasis of the wound bed is achieved. Electrocautery should be used sparingly so as not to induce thermal injury and add necrotic tissue to the vascular wound bed.

Harvesting the Graft

- The graft should be harvested after the final size of the wound is determined.
- Set up the dermatome and adjust to the desired depth and width. The depth of harvest is precisely set in increments of 1/1,000 in. using an adjustable knob on the side of the dermatome. Guard plates come in 1–4 in. widths and are screwed securely (hand tight) into the base of the dermatome, immediately over the disposable blade. If the guard is not secured appropriately, the depth of harvest is unreliable. It is important to check the depth knob and screw tightness prior to harvesting a graft.

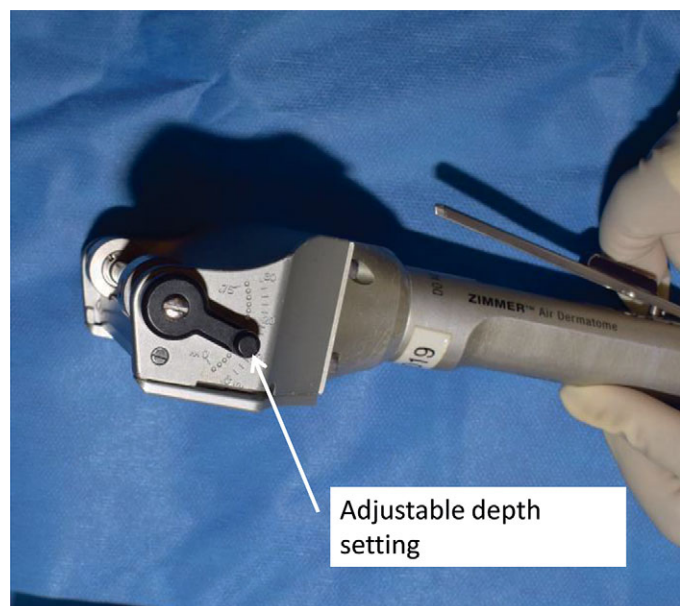
**Figure 46.4** Dermatome with adjustable depth knob.



Figure 46.5 Skin graft harvest technique with assistant creating broad flat surface with tension. Marked lines indicate dimensions of graft to be harvested.

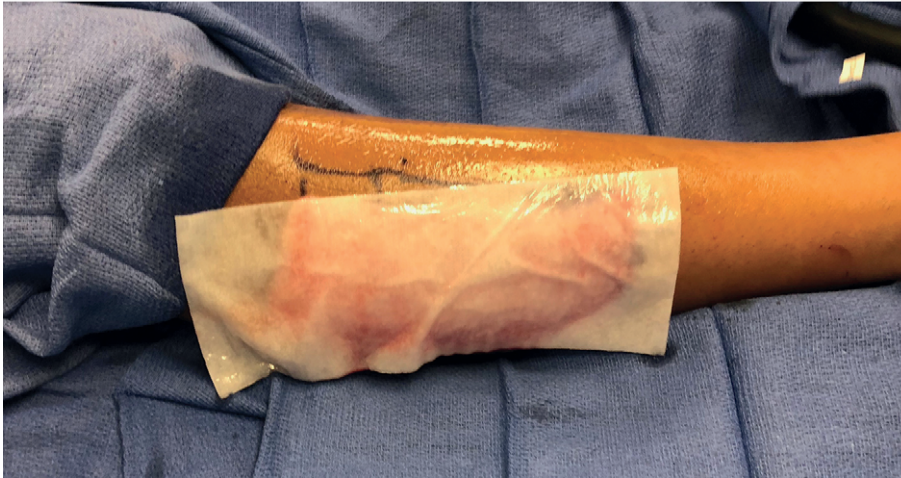
- Clean the donor site with wet gauze to remove any residual sticky surgical preparation solution (such as chlorhexidine) that may cause the dermatome to jump or skip. Apply mineral oil or another lubricating agent to the skin.
- To activate the dermatome, release the safety and depress the lever on the handle. If air-powered, the pressure setting should be 100 psi while the dermatome is active. A high-pitched whine confirms adequate power.
- Use a surgical assistant to create a broad, flat surface where the dermatome can be easily passed. Lap sponges or towel clamps are helpful to stretch the skin and provide traction in difficult areas. Inject saline into subcutaneous tissue to smooth out areas of variance in contour (e.g., posterior thoracic rib cage).
- Now, harvest the graft. The dermatome should be powered on and active prior to contact with the skin and until lifted away from the body. To harvest the graft, contact the skin with the dermatome at a 45° angle. Maintain even downward pressure along the leading edge of the dermatome. Drop the angle of the dermatome to the skin to 30° and apply slow but steady forward pressure to advance and harvest the graft. When the endpoint of graft is reached, push the hand downward and lift the dermatome from the skin in a “fly away” or “take-off” motion. After the graft is harvested and the dermatome is no longer touching the skin, release the lever, deactivate the dermatome, and reapply the safety.

(a)



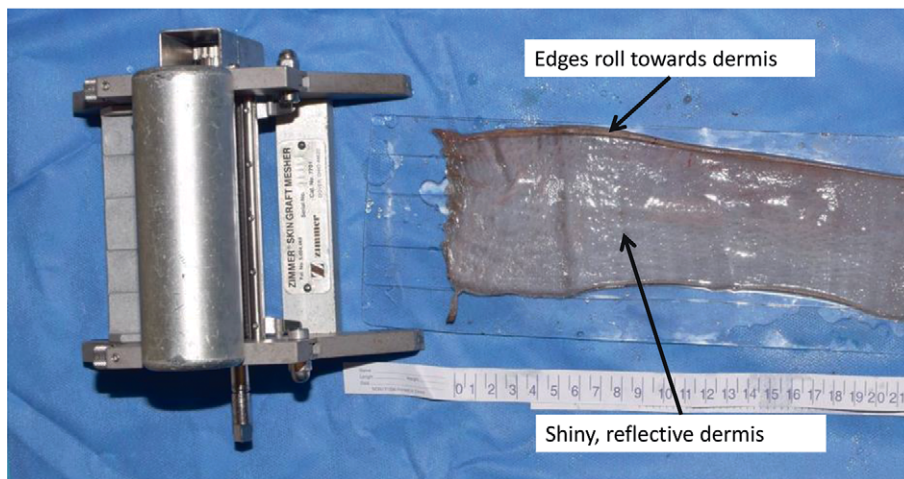
Figure 46.6 (a) Right Leg donor site after graft harvest. **(b)** Right Leg donor site with epinephrine soaked gauze for hemostasis.

(b)

**Figure 46.6** (cont.)

- Dress donor site immediately in a nonadherent gauze pad soaked in dilute epinephrine solution to limit blood loss (Figure 46.6b).
- If the graft is to be meshed, remove the graft from the dermatome and transfer to a carrier. Spread the graft evenly and flatly on the carrier and note which side the dermis is facing. The dermis will appear as white, shiny, and moist; the epidermis is matte, pigmented, and may have hairs. The skin graft edges roll toward the dermis.
- Ensure the skin graft mesher or the carrier is calibrated to the appropriate mesh ratio; devices differ in how this is achieved, so some familiarity with the product is required. Insert the carrier into the mesher and mesh by cranking the lever, which advances the carrier and graft through the meshing wheel.

(a)

**Figure 46.7** (a) Skin graft dermis side uploaded into mesher, dermis side up. (b) Appearance of skin graft after meshing at 2:1.

(b)

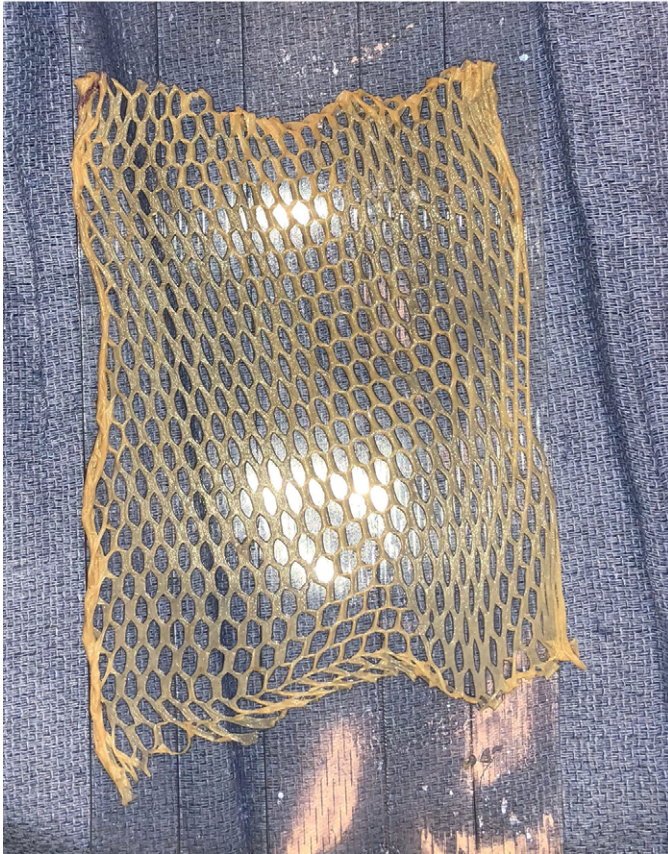


Figure 46.7 (cont.)

Graft Placement

- Place the graft dermis side down in the wound and contour it precisely in three dimensions, so it is entirely in contact with the wound bed. Eliminate any air bubbles or dead space beneath the graft. Trim the graft edges to oppose or slightly overlap the margins of the wound into normal skin. Any gaps between the graft edge and wound margin will have prolonged healing time and likely develop a hypertrophic scar.
- Secure the graft to the wound edges with sutures or staples. A thin layer of slow-clotting fibrin glue may be sprayed on the wound bed immediately prior to securing the graft. Fibrin glue is expensive, but improves the adherence of the graft and decreases or obviates the need for staples at the wound margin.

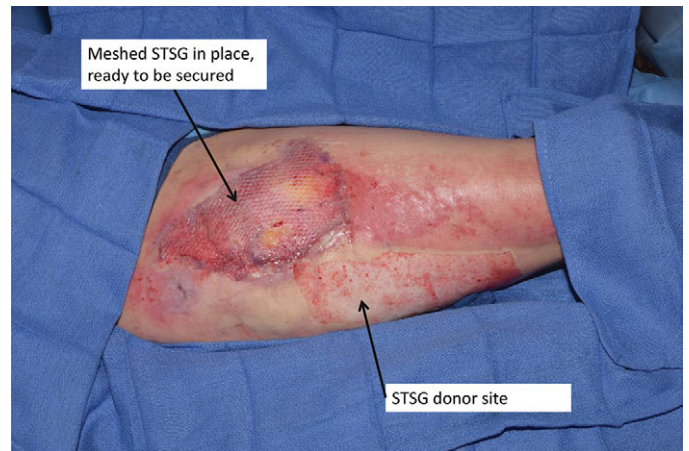


Figure 46.8 Meshed skin graft in place and ready to be secured.

Graft Dressing and Immobilization

- Place a nonadherent contact layer between the graft and outer dressing layers of dressing to prevent the graft from being pulled away from the underlying bed on removal of the dressing. Inclusion of topical antimicrobial therapy, such as sustained release silver or irrigating solutions, to graft dressings is recommended to limit bacterial growth and decrease infection during graft take.
- Dress the graft with a compressive dressing to maintain moisture and immobilize the area. Compressive dressings should apply equal and even downward pressure on the skin graft over the entirety of the wound.
- Use splints or other immobilizing devices both, one joint above and below the area of graft placement. Joint motion during graft healing can cause graft loss.
- Techniques for dressing are variable and include circumferential compression wraps for extremities, foam bolsters, tie-over bolsters, and negative pressure wound therapy (NPWT). While no definitive superior technique exists, NPWT is increasingly utilized, as the technology is familiar and easy to use. This method has been associated with decreased pain on removal, but may be prone to device failure if the vacuum seal is inadequate.

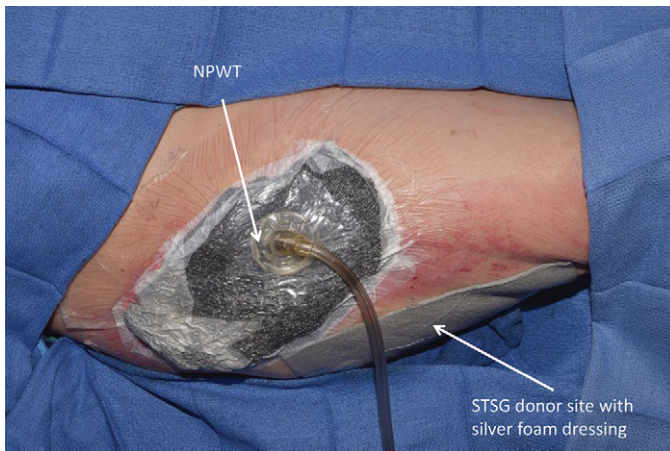


Figure 46.9 Skin graft dressed with NPWT. Donor site dressed with sustained silver releasing nonadherent foam. NPWT, Negative Pressure Wound Therapy.



Figure 46.10 Right Leg 7 days post-op, demonstrating excellent graft take.

Donor Site Dressing

- There are a number of donor site dressings that are used, and practices vary among institutions and clinicians. General principles of wound healing apply: the optimal dressing should maintain a moist, pathogen free environment, control excess exudate, and limit the number of painful dressing changes. Sustained release, silver impregnated foam is our preferred donor site dressing.

Post-operative Management

Sheet Grafts

- Remove dressings after 2 days to evaluate for the presence of hematomas or seromas underneath the graft. If encountered, lance with an 18-gauge needle and evacuate gently by rolling out with a cotton-tipped applicator.
- Redress the graft with a compressive dressing and leave in place for another 2–3 days.

Meshed Grafts

- Keep in the surgical dressing for 4–5 days, while graft maturation occurs. After initial dressing takedown, continue dressing with topical antimicrobials over the graft and interstices until wound healing has completed and the interstices have contracted to closure.
- Moisturize the graft and donor sites after restoration of the epithelial barrier. Moisturizers are necessary over the skin graft since dermal appendages are no longer present and the graft is not capable of moisturizing itself.
- Duration of immobilization and dressings are at the discretion of the clinician. Begin range of motion after the

grafts are deemed sufficiently mature and stable. Physical and occupational therapy should be initiated at this time to prevent functional deformities related to graft contracture.

Tips and Pitfalls

- Grafts rely on a vascular wound bed for success. Dermis, fat, fascia, muscle, paratenon, periosteum, and granulation tissue can support a successful skin graft. Bone devoid of periosteum, tendon without paratenon, exposed foreign bodies such as orthopedic plates or vascular grafts, or irradiated dermis do not support a skin graft and will need alternative methods of wound closure.
- Adequate graft immobilization and careful dressing placement intraoperatively and postoperatively, as well as meticulous hemostasis during the procedure prevent poor graft take.
- Infection and graft loss may occur if the wound has not been adequately cleared of pathogens. Local wound care with topical antimicrobials or surgical excision are viable methods of achieving a clean wound bed prior to graft placement.
- Dermatome “skipping” is common in inexperienced hands and can result in an unusable graft. Equal and steady downward pressure on the dermatome, a correct angle of approach, and adequate traction and skin lubrication can help prevent this complication.

Negative Pressure Therapy for Soft Tissue Wounds

Elizabeth R. Benjamin and Demetrios Demetriades

General Principles

- Negative pressure wound therapy (NPWT) provides a closed, moist environment with a regulated level of negative pressure to the wound bed, stimulating perfusion and granulation tissue formation, reduction of local edema, removal of infected fluid, and wound volume contraction.
- NPWT can be used in a variety of wounds, including large traumatic wounds, fasciotomy sites, skin grafted wounds or burns, necrotizing soft tissue infections, infected orthopedic hardware or joints, and wounds with exposed or infected bone or tendon.
- The recommended optimal negative pressure is 125 mmHg.
- Veraflo therapy is a specialized wound dressing that combines negative pressure therapy with automated intermittent wound irrigation. The system instills irrigation fluid into the wound, allows soaking of the wound for determined period of time (usually 10–20 minutes), followed by negative pressure for a defined period of time (usually 3–4 hours). The settings and instillation volume can be customized as needed.
- The principles of soft tissue wound management differ significantly based on whether or not infection is present.
 - For noninfected soft tissue defects, such as large traumatic wounds, operative management is guided by debridement of dead or ischemic tissues and wound approximation, where possible. Negative pressure therapy may be applied as an adjunct to stimulate granulation tissue formation and wound shrinkage.
 - For infected wounds, operative management is guided by debridement of all infected and necrotic tissue. Systemic antibiotics are often necessary for invasive infections. NPWT with intermittent irrigation (VAC Veraflo System) may be locally applied to enhance wound granulation and closure and decrease bacterial burden as well as frequency of debridements.
- Appropriate surgical debridement and wound hemostasis are imperative prior to application of NPWT.
- NPWT reduces the number of surgical debridements, is more comfortable than the traditional dressings, shortens the time to wound closure and hospital stay, and lowers costs.

Equipment

- Commercially available NPWT systems include a pump and disposables specific for the wound needs (Figure 47.1).
 - Foam: the wound is filled with a custom cut sponge. Wound needs dictate the type of sponge used
 - Granufoam: standard black foam
 - Granufoam silver: silver impregnated foam
 - Not recommended for use in combination with irrigation system
 - White foam: polyvinyl alcohol-based foam designed to reduce tissue adherence and the sponge of choice over vessels, nerves, or granulating viscera
 - Cleanse Choice: waffle-cut foam designed to mechanically debride wounds during suction and irrigation therapy.
 - Irrigation Fluid
 - Saline, Dakin's solution, sulfamylon, acetic acid, or antibiotic solution, are some of the solutions used for wound irrigation. No solution is superior to another, and solution type is based on provider discretion and the type of organism cultured from the wound.

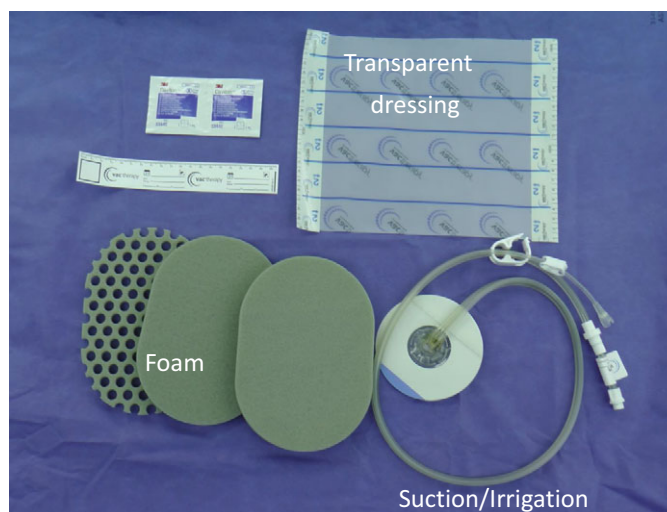


Figure 47.1 Commercially available NPWT system with ruler, foam (Cleanse Choice pictured here), transparent dressing, and suction and irrigation ports.

Technique

- Surgical excision of all devitalized tissue and drainage or unroofing of abscess cavities is necessary prior to placement of negative pressure therapy.
- Vessels, nerves, and exposed viscera are covered with Vaseline impregnated gauze and/or the special nonadherent white foam.
- Cut foam to fit size and depth of wound. Foam trimmed just smaller than the observed wound can help decrease wound volume once negative pressure is applied.
- Black Granufoam is the most commonly used dressing; however, consider a Cleanse Choice dressing in severely infected wounds (Figure 47.2a). When using the Cleanse Choice dressing, the waffle-cut foam is covered with an additional layer of foam (Figure 47.2b).
- Cover foam with a transparent adhesive dressing. Make sure there is a watertight seal circumferentially around the wound. Leaks will inhibit effective NPWT phase and progress with the irrigation therapy phase.
- Cut a 1-cm hole in the transparent adhesive dressing to allow communication between the suction/irrigation port and the foam dressing (Figure 47.3a, b).
- If Veraflo System is to be used, there is an option for combined or separated irrigation and suction ports for larger wounds. If using separate irrigation and suction ports, place the irrigation port superiorly on the wound and the suction port in a dependent position.
- Determine settings on the pump for irrigation volume, soak and interval times, and level of negative pressure therapy (Figure 47.4a–c).
- The instill volume can be estimated using the “fill assist” function. On initial installation, manually halt instillation when the volume instilled results in near complete color change of the foam (Figure 47.5). This instilled volume will be calculated and stored by the pump for future cycles. The instillation volume can be manually changed at any time, but this function allows for an initial estimate based on the wound size. Another method of approximating instillation volume is to use 0.2 mL/cm² of wound area.
- Standard initial presettings:
 - Instill volume: 10 mL. The volume is determined by the size of the wound
 - Soak time: 10 minutes
 - Negative pressure therapy: 3.5 hours
 - Target pressure: –125 mmHg
- For adjacent wounds, a bridging technique can be used (Figure 47.6a, b). Individual wounds are dressed with foam as above. A skin-protective layer is placed between the wounds using either a Vaseline-impregnated gauze or a piece of transparent adhesive dressing. A standard piece of

Granufoam is placed on top of this protective layer to connect the two adjacent foam wound dressings. This bridge will allow irrigation and suction to traverse the two wounds.

- Never connect an infected and noninfected wound.
- If using Veraflo with this bridging technique, strategically place the irrigation port to allow gravity to assist with irrigation flow to all areas of the wound dressing.
- NPWT can be changed every 3–5 days, depending on stability of the wound, degree of local devitalized tissue, and systemic disease burden. After 5 days, the granulation tissue grows into the foam and becomes very difficult and painful to remove the dressing.
- Once the wound is clean and an adequate granulation bed is present, the wound may be covered with split thickness skin graft (Figure 47.7a–c).

(a)



Figure 47.2 Cleanse Choice waffle-cut foam used as the base layer after surgical debridement of a necrotizing soft tissue infection (a). This layer is covered with a second layer of foam, custom cut to fit the wound (b).

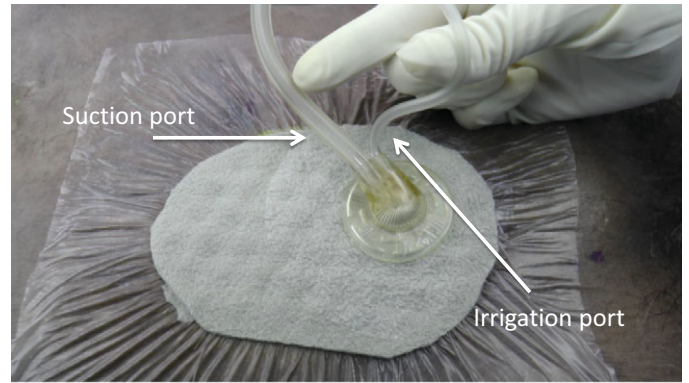
(b)

**Figure 47.2** (cont.)

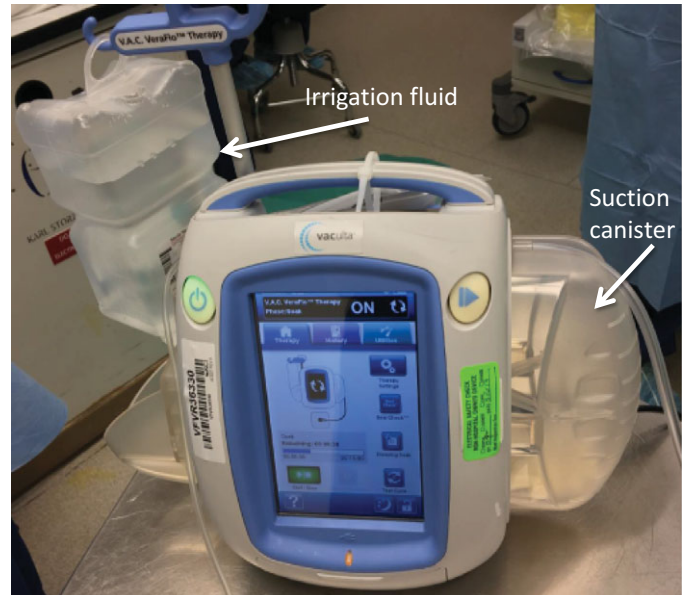
(a)

**Figure 47.3** After the foam is covered with a transparent dressing and a 1 cm hole is cut in the dressing, the suction/irrigation port is applied to the wound dressing (a). This is a dual component device with a suction and irrigation port combined in one attachment (b).

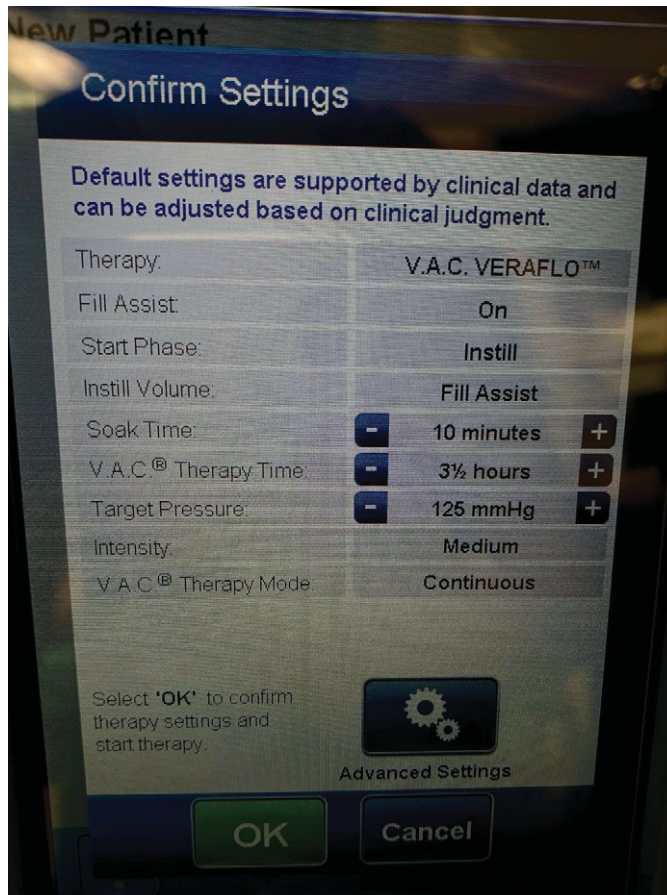
(b)

**Figure 47.3** (cont.)

(a)

**Figure 47.4** Using the Vaculta machine, the Veraflo mode can be selected. The irrigation fluid and the suction canister are connected to the base pump and the settings are modified, based on clinical scenario (a). Default settings for the Veraflo system (b). Using the fill assist function, the volume of irrigation solution is set and stored in the machine for future cycles (c).

(b)



(c)

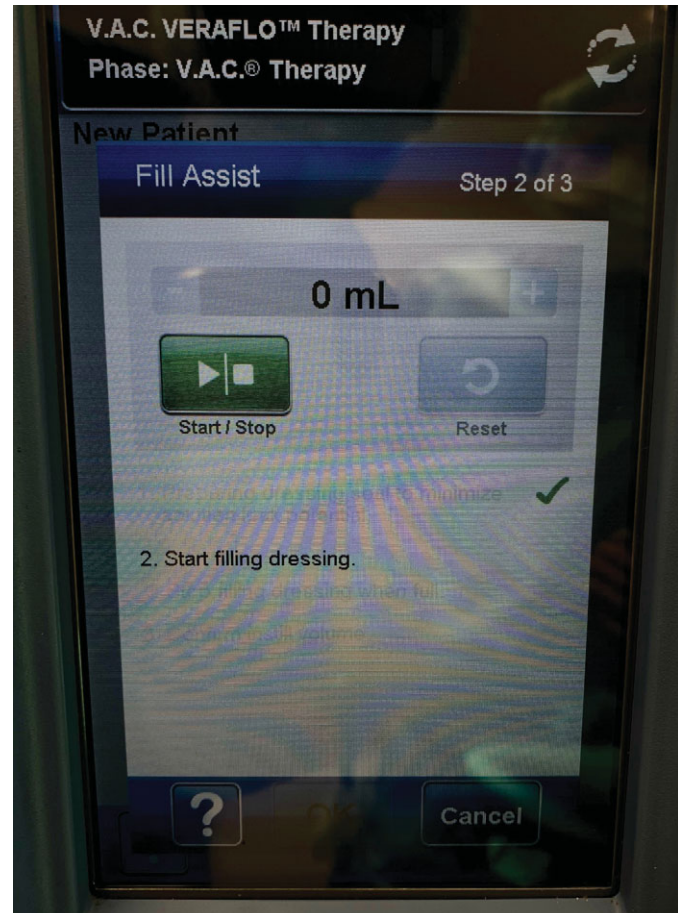


Figure 47.4 (cont.)

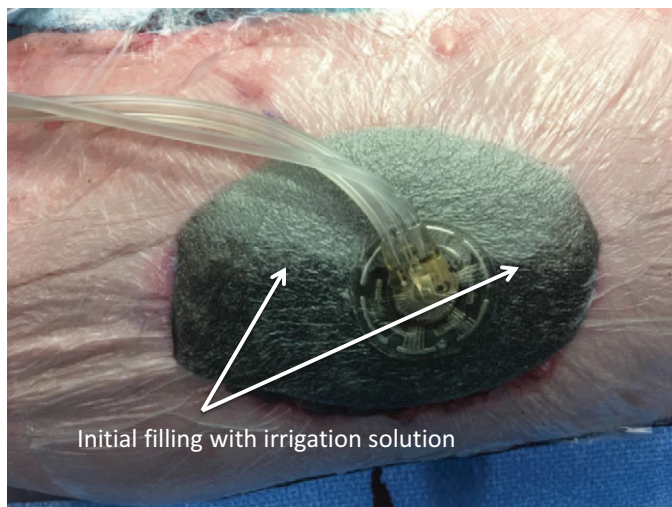


Figure 47.5 As instillation volume is added and wound saturation occurs, note the color change of the sponge. Use the near complete color change of the sponge to determine irrigation volume needed.

(a)



Figure 47.6 (a) Multiple adjacent wounds requiring Veraflo system. **(b)** Wounds are bridged to allow a single irrigation and suction system for multiple wounds. The separated irrigation and suction ports are used to allow full distribution and removal of the irrigation solution.

(b)

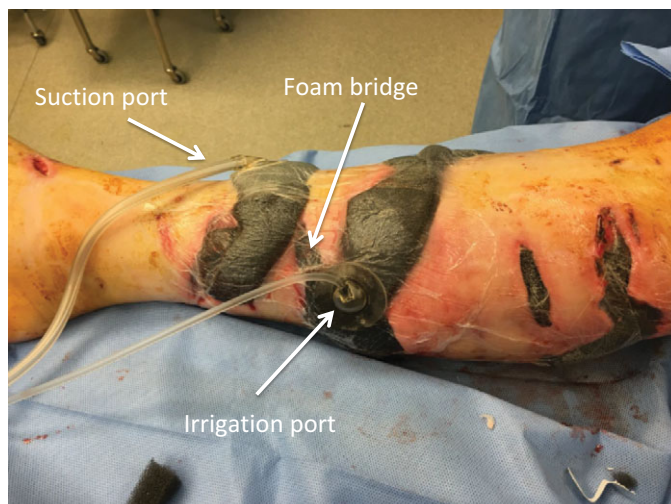


Figure 47.6 (cont.)

(a)



Figure 47.7 Severe necrotizing soft tissue infection requiring extensive debridement of the lower extremity (a). After debridement, the wound was treated with the Veraflo system (b) and ultimately covered using a split thickness skin graft (c).

(b)



(c)



Figure 47.7 (cont.)

Tips and Pitfalls

- Negative pressure therapy is an absolute contraindication in patients with incomplete hemostasis, and application of negative pressure therapy in this setting can result in significant hemorrhage and death. Monitor canister regularly for any bleeding, and stop negative pressure therapy with any signs of significant hemorrhage.
- Under no circumstance should black foam come in contact with vessels, nerves, or exposed viscera.
- VeraFlo NPWT may salvage infected orthopedic hardware.
- If the NPWT phase alarms due to inadequate seal, apply additional transparent adhesive dressings to leak points. If adequate seal is not achievable and suction cannot be maintained, remove the foam dressing and replace with standard gauze or other dressing.

Escharotomy in Burns

Justin Gillenwater and Warren Garner

General Principles

- Deep partial thickness and full thickness circumferential or near circumferential burns of the neck, chest, abdomen, or extremities can cause serious local or systemic complications and need surgical release of the burn eschar to relieve obstruction or high pressures and restore perfusion.
 - Circumferential burns of the neck can cause airway obstruction.
 - Circumferential burns of the chest can cause respiratory compromise with increased peak inspiratory pressures, hypoxia, and hypercapnia.
 - Circumferential burns of the abdomen can cause intra-abdominal hypertension and abdominal compartment syndrome.
 - Circumferential burns of the extremities can cause muscle compartment syndrome.
- Deep partial or full thickness circumferential extremity burns require prophylactic escharotomy.
- Near circumferential extremity burns require frequent neurovascular checks to assess for need of escharotomy. Worsening neurovascular exam or pressure measurement >30 mmHg should prompt urgent escharotomy of the affected extremity.
- In severe burns requiring massive fluid resuscitation, abdominal or extremity compartment syndromes may develop independent of circumferential burns. It is important that these high-risk patients are monitored closely and decompressive laparotomy or extremity fasciotomies are performed timely in the appropriate cases.

- Electrical burns or burns associated with crush injuries may require fasciotomies, in addition to escharotomies, to restore adequate perfusion.

(a)



(b)



Figure 48.1 (a) Circumferential full thickness bilateral leg burns requiring escharotomy. (b) Circumferential full thickness right arm burns requiring escharotomy.

Equipment

- Special equipment is not necessary to perform an escharotomy, and all supplies are widely available to all hospitals and operating rooms.
- A warming blanket or heat lamps to prevent hypothermia.

Technique

General

- The patient should be covered and normothermia preserved during the procedure. Each affected body area should be uncovered, fully released, and re-dressed sequentially to avoid exposure of the total body and prevent hypothermia.
- Use a surgical marking pen to draw out the incisions for release. The markings should extend at least 1 cm past the burn and into normal skin.

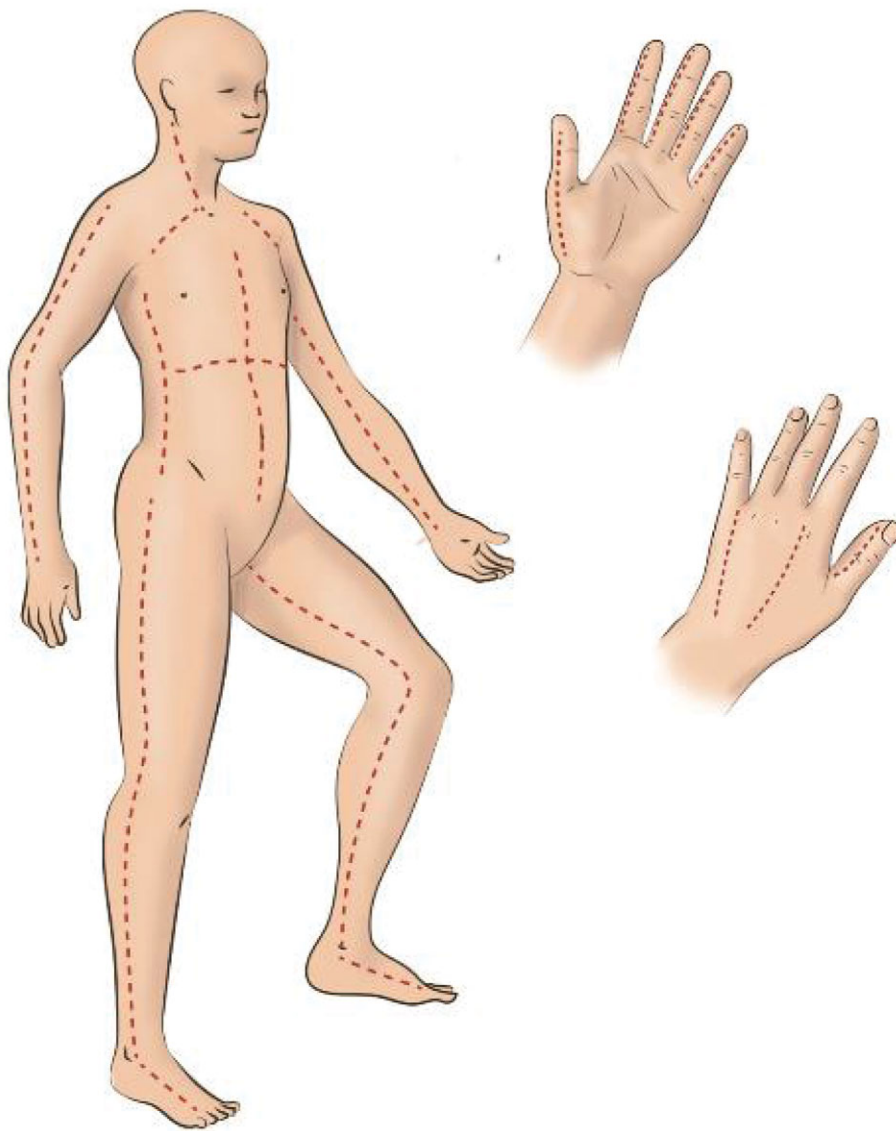


Figure 48.2 Incisions for common escharotomies in the trunk and extremities.

- Use electrocautery to divide through the burned skin and into subcutaneous tissue. Often, the superficial fascia (Scarpa's) will require release as well. The deep fascia should not be violated. Adequacy of release is confirmed by return of function or perfusion as described below. The released area should be soft globally with no constrictions at any point. Re-release is performed as necessary.
- After release, the underlying musculofascial compartments are palpated and should be soft and compressible. If tight, the deep fascia may be scored to see if muscle bulging is occurring, which may indicate the need for fasciotomies. If escharotomies are adequate but perfusion is not restored, fasciotomies may be required and performed in standard fashion.
- Use cautery or suture ligation to achieve meticulous hemostasis after verifying adequacy of release.
- Dress and cover incision sites at the same time as the burn wound.

Torso

- Draw a shield like pattern on the chest wall and abdomen. The anatomic landmarks are: the bilateral midaxillary lines from the axilla to the anterosuperior iliac spine, superiorly across the clavicles, and inferiorly at the costal margin and the suprapubic region.
- Perform release using cautery as described above. After release, the chest wall is observed for symmetric bilateral excursion and abdomen is palpated. The chest wall and abdomen should move freely, and ventilation should occur without impedance from the burn wound. The bladder pressures can be rechecked if previously elevated.
- Additional releasing incisions or crosshatching of the unreleased eschar may be performed as necessary, if the initial releases were inadequate to regain functional chest wall compliance.



Figure 48.3 (a, b) Escharotomies of the chest. The incisions should include midaxillary lines, ventral midline. The burn is incised fully through eschar and dermis, down to subcutaneous fat.

Arm and Forearm

- Draw medial and lateral midaxial incisions along the length of the arm and forearm. The incisions are designed to prevent damage to superficial structures, which include: the ulnar nerve at the median epicondyle of the elbow, the radial artery at the wrist, the brachial artery and large veins in the antecubital fossa, and the medial intramuscular groove between the biceps.
- Perform release using cautery as described above. Recheck perfusion distally. A vascular exam with improved distal perfusion and restoration of palpable pulses indicates a suitable release. Consider the need for an additional fasciotomy, if perfusion not restored.

(a)



(b)



(c)



Figure 48.4 (a) Circumferential burns of the right forearm and hand requiring escharotomy. (b) Marking of the escharotomy of the radial border. (c) Completed escharotomy of radial border. (d) Marking of the escharotomy of the ulnar border of the right forearm and hand. (e) Completed escharotomy of the ulnar border.

(d)



Figure 48.4 (cont.)

(e)



Hand and Digits

- Draw escharotomy markings from the arm into the dorsum of the hand and fingers as one continuous release. If isolated hand burns, two dorsal releasing incisions are drawn. Digital releases should be considered by extending the incisions through the second to fourth digital web spaces and onto the fingers. The fingers are marked at the mid axial line, where the glabrous skin transitions to hair bearing skin. The ulnar border of the index, long, and ring fingers and the radial border of the small finger are selected to minimize morbidity should damage occur to the digital neurovascular bundles during release.
- Perform the release using cautery. A hemostat can be used to spread through deeper structures after a superficial release to avoid injury to the neurovascular bundle in the fingers. Recheck perfusion distally after completion of the escharotomy. The deep palmar arch and digital arteries can be assessed with a transcutaneous Doppler, capillary refill can be seen in the nailbed, and a pulse oximeter can be used on a fingertip to (if unburned) confirm restoration of flow. Consider additional fasciotomy of the hand if perfusion is not restored.

Lower Extremity

- Mark incisions along the medial and lateral axis of the lower extremity. Incisions are designed to prevent damage to the superficial structures, including: neurovascular structures in the popliteal fossa, the neck of the fibula where the peroneal nerve courses, and the posterior aspect of the medial malleolus with posterior tibial artery and nerve. If possible, the greater and lesser saphenous veins and the sural nerve should be identified and spared.
- Dorsal foot releases should be performed if there are circumferential foot burns. Toe releases are generally not indicated.
- Perform release using cautery. Recheck perfusion distally after completion of the escharotomy. Dorsalis pedis and posterior tibial pulses can be palpated or, in the setting of extreme swelling, assessed with a transcutaneous Doppler. The plantar arch can be assessed with a transcutaneous Doppler, capillary refill can be seen in the nailbed, and a pulse oximeter can be used on a toe to confirm restoration of flow.

(a)



(b)



(c)



(d)



Figure 48.5 (a) Circumferential burns of the left leg requiring escharotomy. (b) Marking of the medial incision for escharotomy of the left leg. (c) Completed medial escharotomy of the left leg. (d) Left leg lateral before escharotomy. (e) Marking of the escharotomy of the lateral left leg. Note position of peroneal nerve. (f) Completed escharotomy of the lateral left leg.

(e)



Figure 48.5 (cont.)

(f)



Tips and Pitfalls

- Escharotomies are simple, safe, and without complication, if done correctly. Good knowledge of surface anatomy and appropriate incision design are necessary to prevent damage to underlying structure.
- The most common complication of escharotomy is an inadequate release.
- Significant bleeding from inadequate hemostasis may occur postoperatively.
- Abdominal or extremity compartment syndromes may develop independently in severe burns requiring massive amounts of fluid resuscitation. Bladder and extremity compartment pressures should be monitored and a decompressive laparotomy or extremity fasciotomy performed, in addition to the escharotomy in this scenario.



Figure 48.6 Escharotomy with inadequate release and ongoing constriction (circle).

Temporary Vascular Shunts

Morgan Schellenberg, Travis M. Polk, and Paul Wisniewski

General Principles

- The indications for shunting after vascular injury include damage control for patients *in extremis*, the presence of associated fractures requiring fixation, the need for transportation to specialized centers for definitive reconstruction, or injury occurrence in an austere environment with limited resources.
- There are a number of commercially available vascular shunts. Improvised shunts can be constructed out of any plastic tubing that has the adequate diameter to match the corresponding vessel, such as chest tubes, intravenous tubing, and feeding tubes. Improvised shunts must be rigid enough that when they are tied into position, the sutures do not collapse the lumen of the shunt.
- When selecting the shunt size for temporary bypass, the largest size of shunt that fits into the injured vessel without forcing it into place should be selected. This will maximize distal blood flow.
- Commercially made shunts should not be trimmed. The edges of commercially made shunts are smooth and designed to avoid trauma to the intima of the artery.
- Improvised shunts should be left long, with redundant length in both the proximal and distal vessel. This will reduce the risk of inadvertent shunt dislodgement.

- The maximum length of time that a vascular shunt can remain in situ is unknown. It is important to perform definitive repair as soon as the patient's physiology and other circumstances allow. Most shunts remain patent for 24–48 hours. The patency of the shunt is confirmed by the presence of a distal palpable pulse or dopplerable signal.

Special Instruments

- For extremity vascular injuries, a peripheral vascular instrument tray is sufficient. This should include vessel loops, a variety of types and sizes of vascular clamps (Bulldogs, Satinsky's, etc.), DeBakey and Gerald forceps, an olive tip syringe, heparinized saline, a variety of sizes of Fogarty catheters, vascular shunts of different sizes, and 0-silk ties.
- For central vascular injuries, such as aortic injuries, thoracotomy or laparotomy sets are required to allow for proper exposure of the injury. The instruments required for these shunts are the same as for the extremity injuries.
- A sterile extremity tourniquet and sterile Doppler probe should be available.

Patient Positioning

- Patient positioning should be performed in the standard fashion for vascular exposure of the injured vessel. Please refer to the appropriate chapter of this atlas for specific instructions.

Technique

- The first step in vascular shunt insertion involves exposure of the injured segment of vessel with vascular control of both the proximal and distal vessel (Figure 49.2).
- The next step involves dissecting both ends of the injured vessel free from the surrounding tissue. The injured vascular ends should not be debrided, in order to preserve as much vessel length as possible for later reconstruction and/or repair.
- Vascular clamps should be placed to both ends of the vessel to occlude blood flow while the shunt is being placed. Bulldog clamps are commonly used for peripheral extremity vascular injuries. Double-looped vessel loops



Figure 49.1 Argyle Shunts. Argyle shunts are one option for commercially made shunts. They are packaged as a set of four shunts, ranging in size from 8 to 14 Fr. The largest size that will fit into the vessel being shunted should be selected in order to maximize distal perfusion.

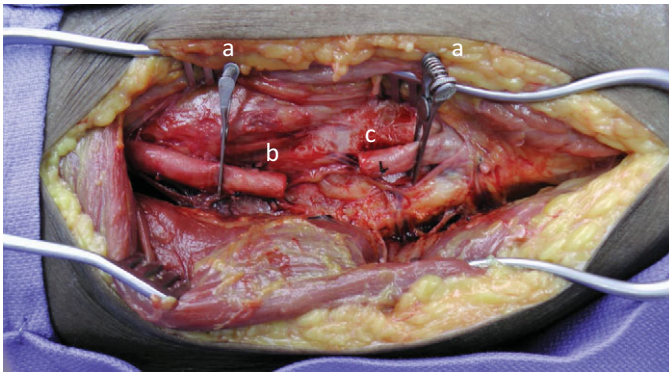


Figure 49.2 Exposure and control of the injury. Using the injured superficial femoral artery (SFA) as an example, vascular exposure is first achieved. Next, the two ends of the injured vessel must be isolated and controlled with vascular clamps, e.g., Bulldogs (a). This allows for control of the proximal (b) and distal (c) ends of the injured artery, facilitating shunt placement in a dry surgical field.

may be utilized as well. Ensure that the vessel loops or clamps are far enough away from the ends of the vessel to allow insertion of the shunt.

- The shunt should be prepared next. The appropriate size shunt is selected, as described above. A 0-silk tie is placed securely around the middle of the shunt (Figure 49.3). The shunt is then flushed with heparinized saline using an olive tip syringe. The tie in the middle will be used later to secure the shunt from dislodging or migrating.
- The distal end of the vessel is prepared first. The Bulldog clamp is removed and a Fogarty catheter is passed to remove any proximal or distal clot prior to shunt insertion (Figure 49.4). The end of the vessel is then flushed with heparinized saline. Back bleeding is confirmed prior to shunt insertion.

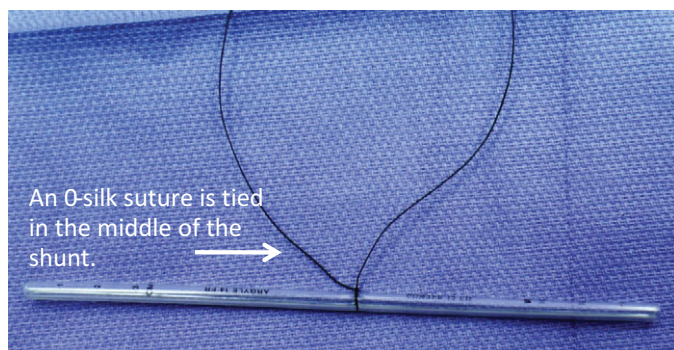


Figure 49.3 Shunt preparation. After obtaining proximal and distal control of the injured vessel, the shunt is prepared. An 0-silk suture is tied to the midpoint of the shunt and it is flushed with heparinized saline.

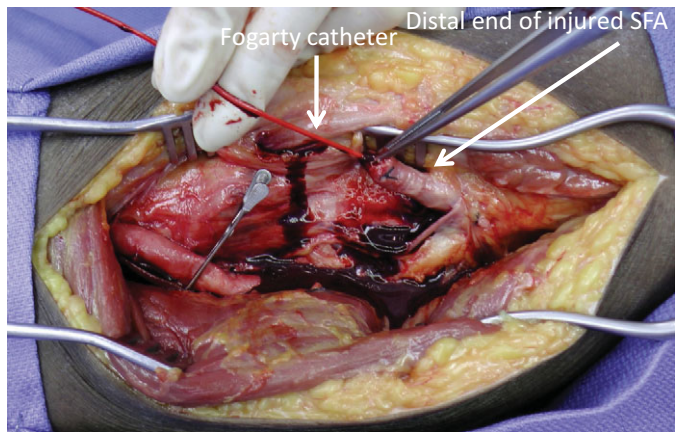


Figure 49.4 Vessel clearance. A Fogarty catheter is passed proximally and distally to extract any thromboemboli and confirm the presence of back bleeding prior to shunt insertion.

- The shunt is inserted into the distal end of the vessel such that the shunt overlaps over a length of 1–2 cm within the vessel. Back bleeding from the vessel should dislodge the column of saline within the shunt (Figure 49.5a). A vascular clamp must be placed to the middle of the shunt to avoid excessive bleeding from the shunt until the proximal end of the shunt can be inserted.
- The proximal end of the vessel is prepared in the same manner as the distal end (Figure 49.5b). Vigorous forward flow must be confirmed prior to shunt insertion. The shunt is then inserted about 1–2 cm within the vessel lumen.

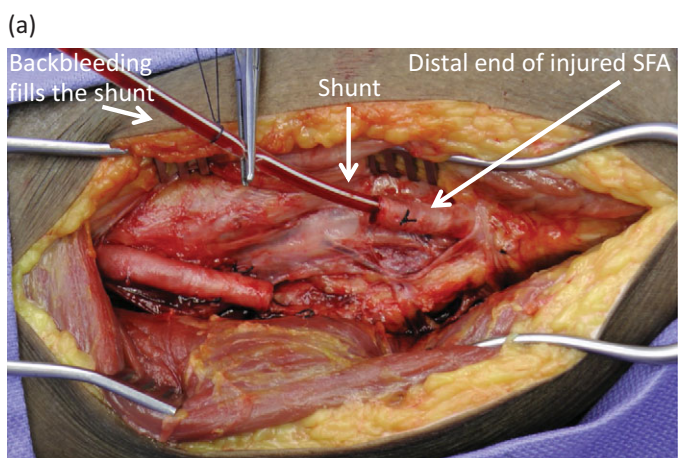
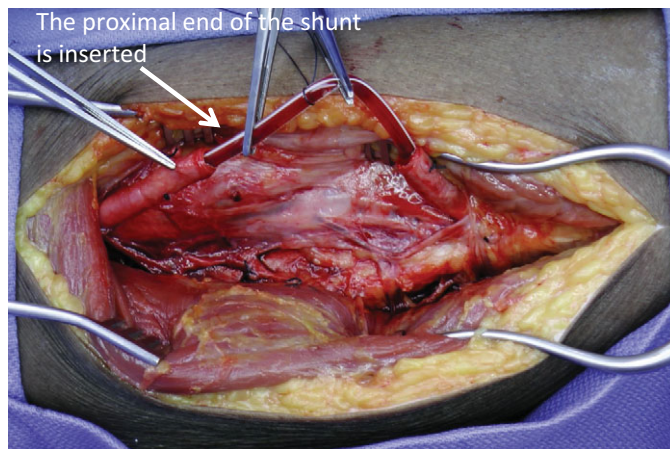


Figure 49.5 Temporary vascular shunt insertion. (a) The distal limb of the shunt is inserted into the vessel over a distance of at least 12 cm. A vascular clamp should be applied to the middle of the shunt to avoid bleeding from the proximal end. (b) The proximal end of the shunt is inserted in the same manner as the distal end.

(b)

**Figure 49.5** (cont.)

- After the shunt has been inserted into the proximal and distal ends of the vessel, a 0-silk tie is passed around each end of the vessel (Figure 49.6a). The shunt is tied proximally and distally to secure it in place in the vessel lumen (Figure 49.6b). The sutures are not cut. The ties on the proximal and distal ends of the vessel are fixed to the tie previously placed in the middle of the shunt (Figure 49.6c). This helps to prevent shunt migration and dislodgement.

(a)

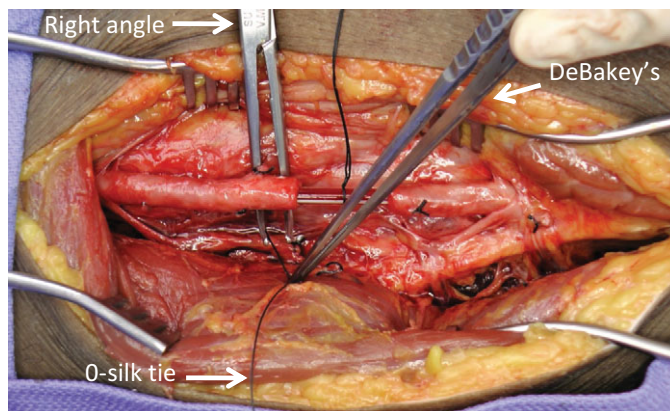
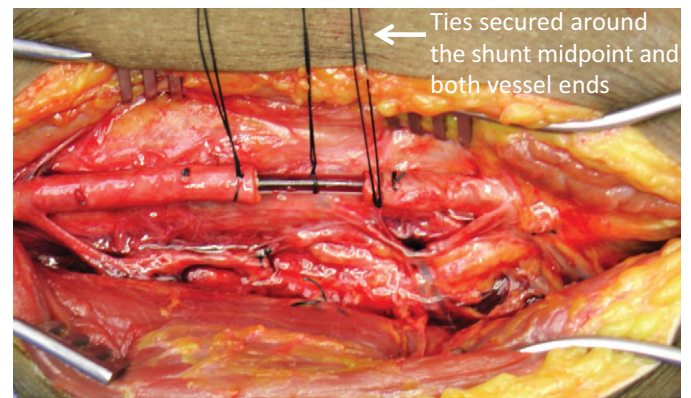
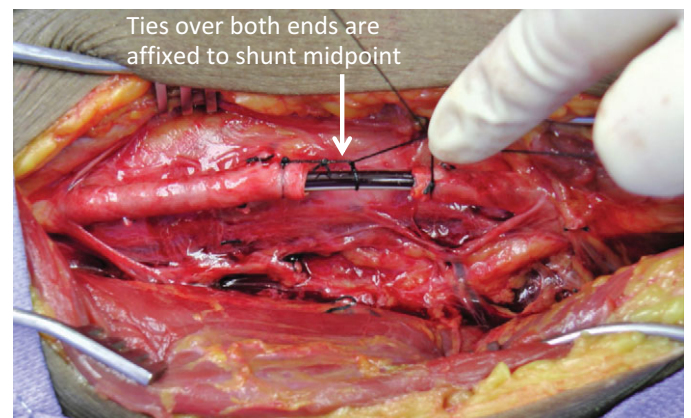


Figure 49.6 Securing the temporary vascular shunt. (a and b) Sutures are tied around the shunt within the proximal and distal ends of the vessel. (c) The ends of the sutures are affixed to the tie around the midpoint of the shunt in order to prevent dislodgement or embolization.

(b)



(c)

**Figure 49.6** (cont.)

- Distal blood flow must then be confirmed with a palpable pulse or Doppler signal. If neither is present, removal of the shunt with attempts at clearing distal clot or an intraoperative angiogram can be undertaken. The patient should not leave the operating room without a distal pulse or an angiogram confirming distal flow.
- A temporary dressing is applied until definitive repair is undertaken.

Tips and Pitfalls

- Select the largest size shunt that can be easily inserted into the damaged vessel. This will serve to maximize distal blood flow.

- Commercially made shunts should not be trimmed. They are designed to be atraumatic to the intima of the artery, a feature which is lost if the shunt is cut.
- Do not trim the injured vessel edges prior to shunt insertion. Additionally, secure the shunt in place proximally and distally with ties placed close to the vessel edge. Do this after the shunt is in place, in case the shunt needs to be manipulated or advanced in any way. These techniques serve to preserve maximum vessel length for future reconstruction and less manipulation of the shunt after placement.
- After securing the shunt proximally and distally, affix these ties to one passed around the center of the shunt to avoid shunt migration and inadvertent dislodgement.
- The patient should not be transported out of the operating room without confirmation of distal flow, i.e., a palpable distal pulse or Doppler signal of the distal vessels.

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